Freeze-Thaw Aluminum Battery: Suppression of Self-Discharge via Thermal Decoupling

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PROJECT PROFILE
Topic: Seasonal Storage / Vertical: Materials and Systems Innovation Strategic Pathway: Accelerating the development and testing of advanced energy storage technology that is more cost-effective, safe , and durable, which is crucial to meeting the Administration's goal of providing reliable, secure, and resilient energy. Project start and finish: FY26

PROBLEM

- Aluminum batteries offer low cost and high safety; however, severe self-discharge limits practical applications
- High-temperature molten-salt electrolytes accelerate energy loss during storage
- Poor energy retention hinders long-duration energy storage applications

APPROACH

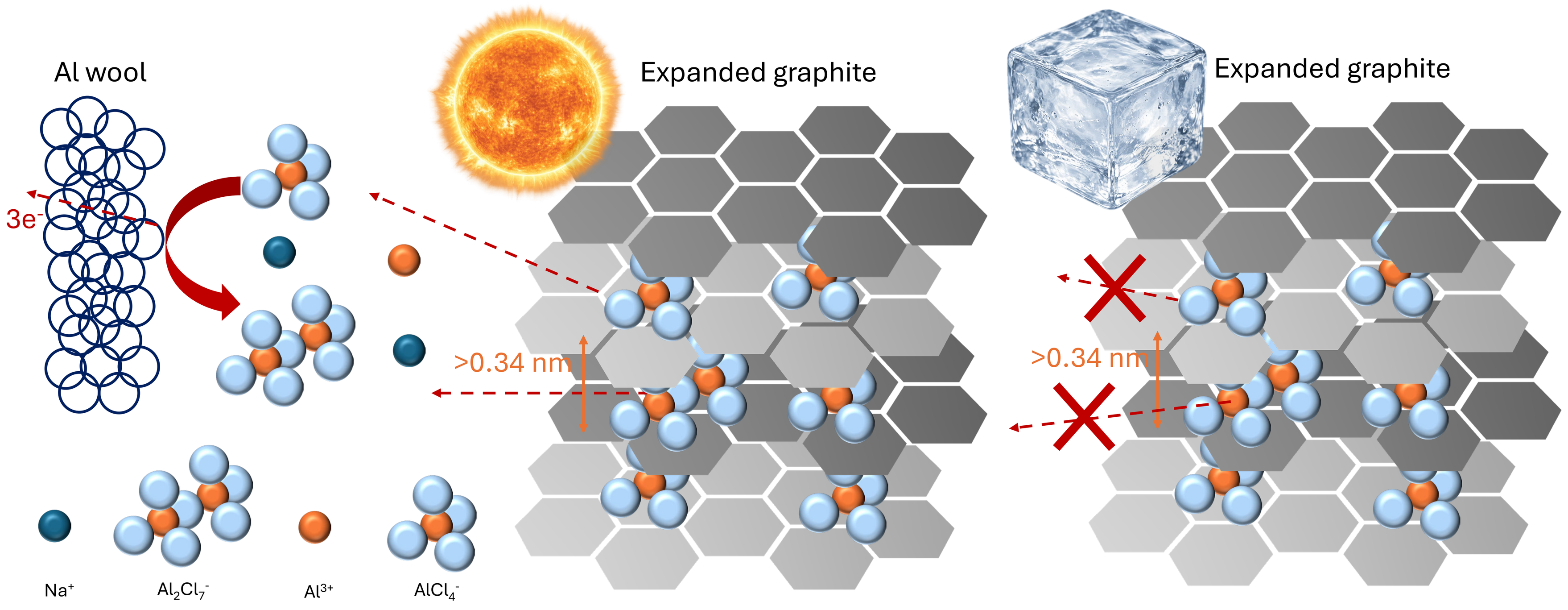

Fig. 1. Schematic illustration of self-discharge suppression in the freeze-state aluminum battery system.

- Developed a freeze-thaw aluminum battery system using an expanded graphite (EG) cathode and $NaAlCl_4$ molten salt electrolyte
- Freezing the $NaAlCl_4$ electrolyte suppresses ion transport and spontaneous deintercalation reactions in expanded graphite, thereby minimizing self-discharge and improving energy retention

RESULTS

- Dry Electrode Processing of Expanded graphite

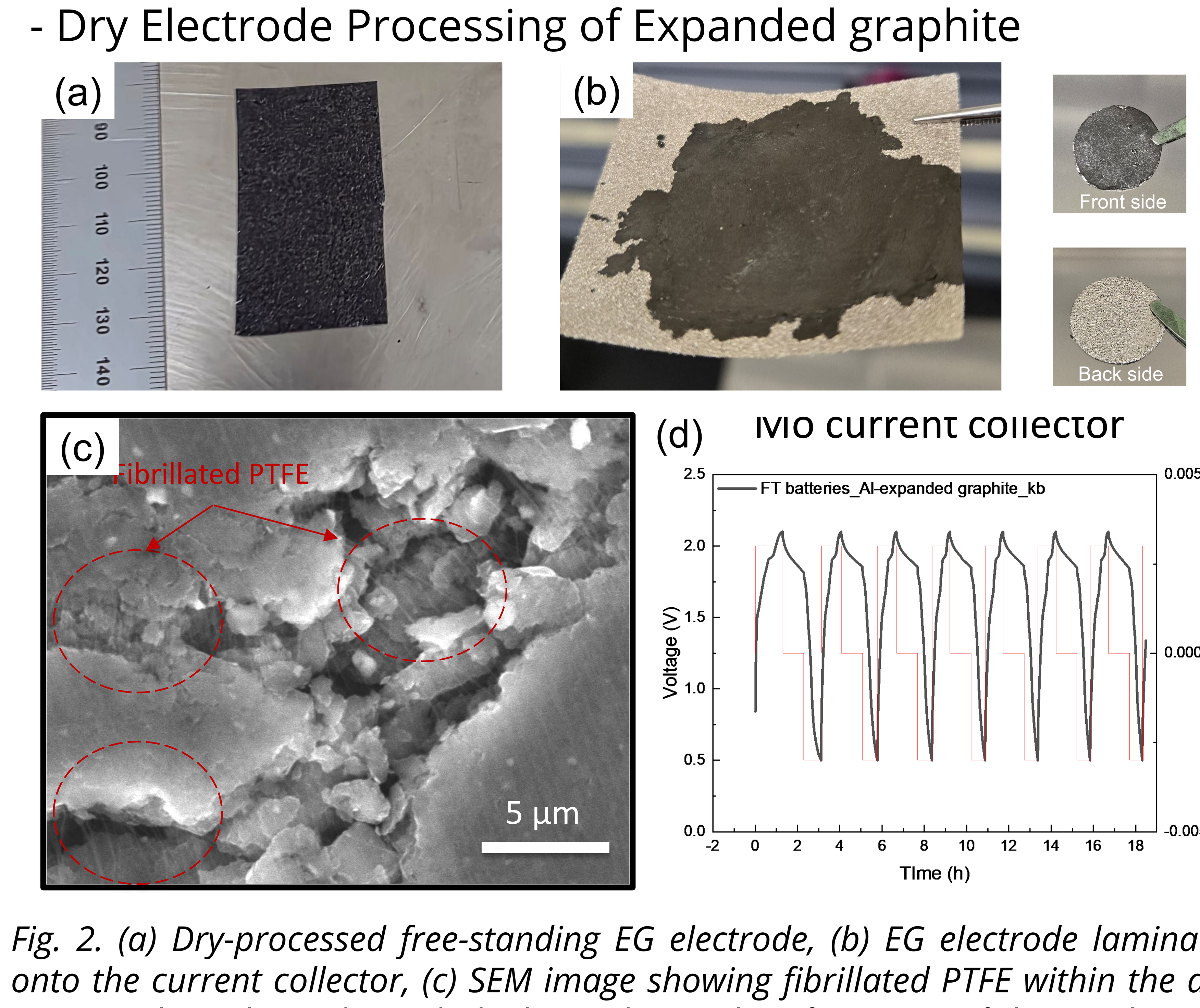

Fig. 2. (a) Dry-processed free-standing EG electrode, (b) EG electrode laminated onto the current collector, (c) SEM image showing fibrillated PTFE within the dry-processed EG electrode, and (d) electrochemical performance of the EG electrode on a Mo current collector

RESULTS

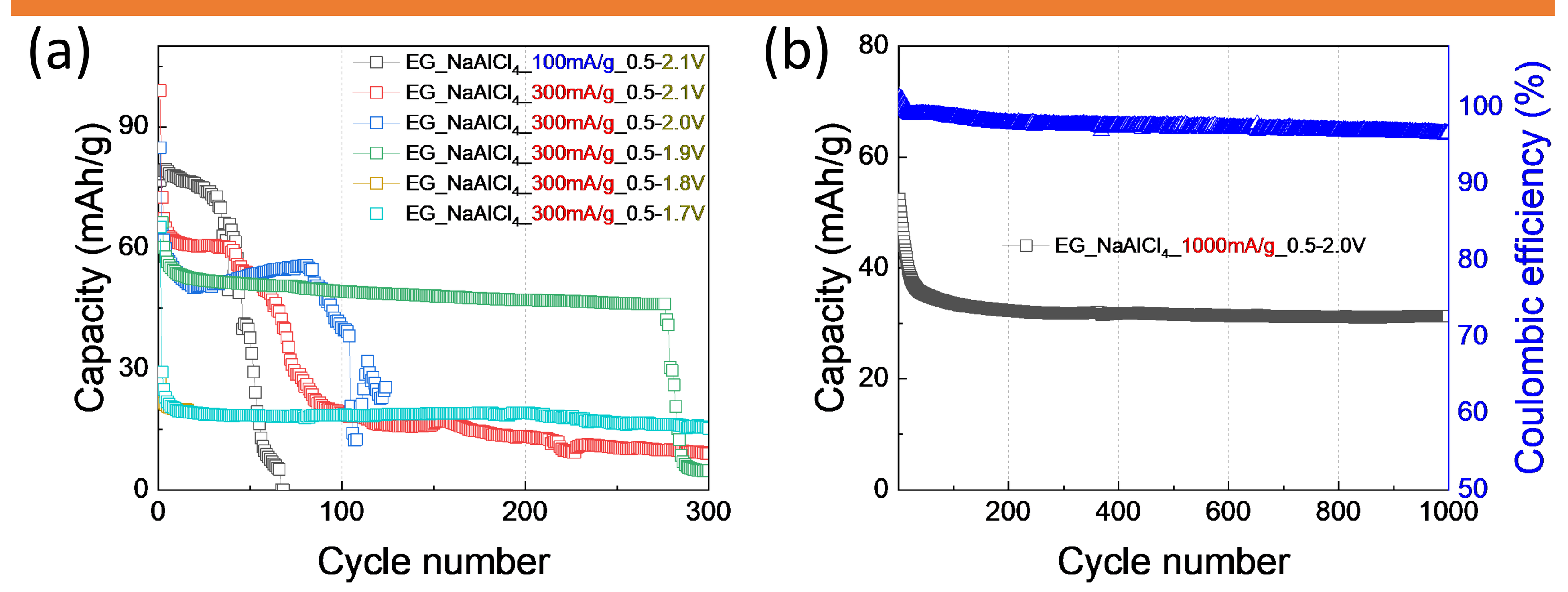

Fig. 3. (a) Cycling performance with different current densities and cutoff voltages. (b) Long-term cycling performance at 1 A/g with a 2.0 V cutoff voltage.

- Lower current density and higher cutoff voltage increased accessible capacity but shortened cycle life due to enhanced self-discharge
- The cell demonstrated significantly improved cycling stability at a higher current density of 1A/g

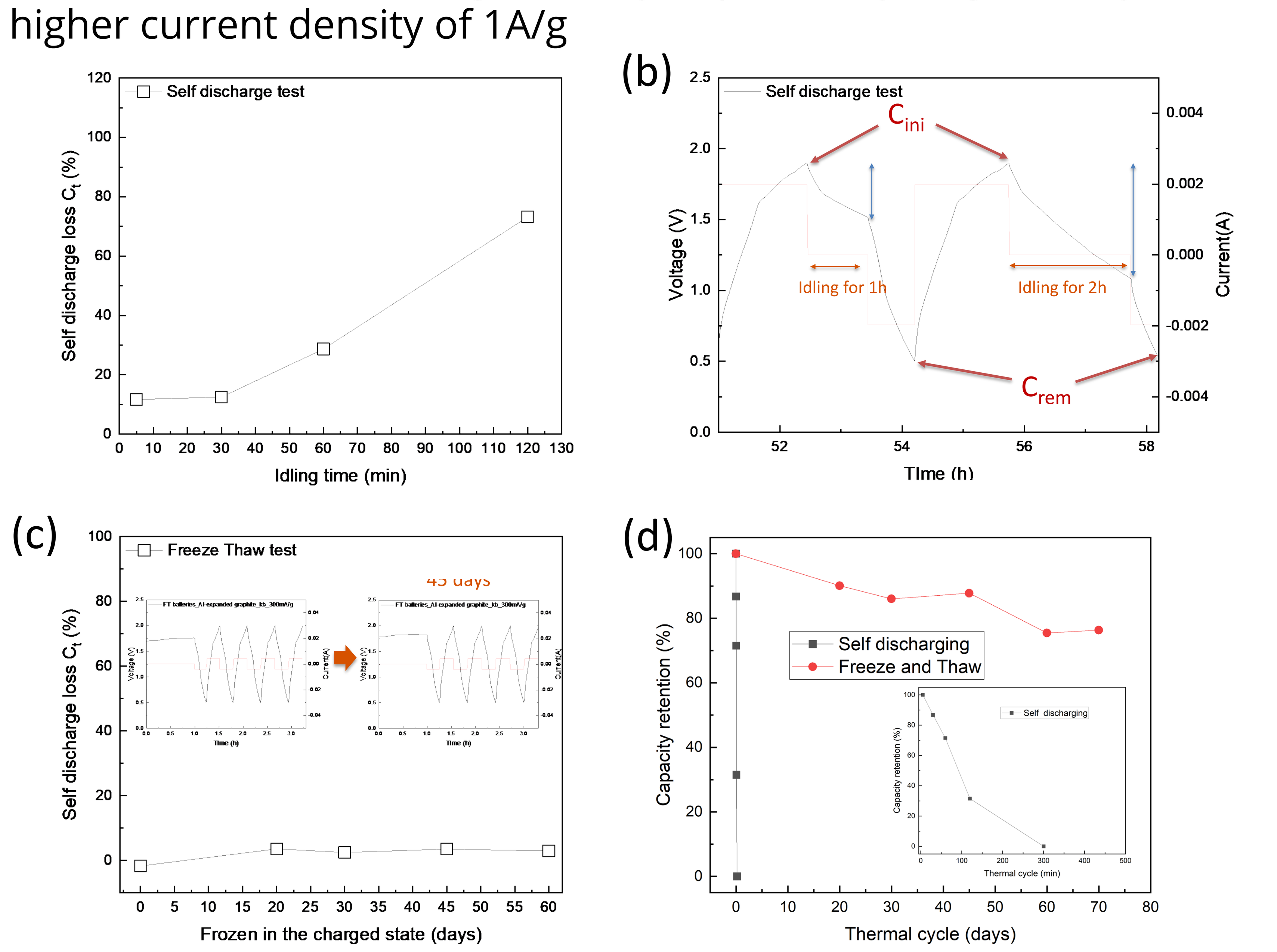

Fig. 4. (a) Self discharge loss with idling time in the thawed state. (b)Schematic voltage-time profile with the initial charging capacity (C_{ini}), remaining discharging capacity (C_{rem}), and idling time during self-discharging test. (c) self-discharge loss in the frozen state at different storage durations. (d) Capacity retention comparison between conventional self-discharge and freeze-thaw storage.

- Self-discharge was significantly reduced after electrolyte solidification
- Spontaneous $AlCl_4^-$ deintercalation reactions were suppressed during storage
- The system demonstrated stable long-term cycling performance under freeze-thaw operation

CONCLUSIONS & IMPACT

- Introduced phase-controlled self-discharge suppression strategy
- Enabled thermal decoupling between operation and storage
- Improved feasibility of seasonal energy storage
- Maintained advantages of aluminum battery chemistry
- Provides a potential pathway for low-cost, safe grid-scale storage

FUTURE DIRECTIONS

- Optimize electrolyte composition for lower operating temperatures
- Improve freeze-thaw cycling stability and durability
- Investigate low-cost cathode and electrolyte materials

References

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2. Joule 7, 619–623, April 19, 2023
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