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Alkaline Earth Stabilized ZnO Electrodes for Rechargeable Batteries

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PROJECT PROFILE
Topic: **Zinc & Lead Batteries** | Vertical: **Materials and Systems Innovation**
Strategic Pathway: **Grow**
Project start and finish: **FY25-FY26**

PROBLEM

Problem: Li-ion batteries dominate grid storage but have significant cost with safety and supply issues.

Motivation: Zinc batteries have proven, domestically sourced materials supply chains and can provide safe and reliable energy storage solutions.

Current practice: Alkaline Zn / MnO_2 batteries are cost effective and widely available as a primary system. Rechargeable (secondary) systems are limited to ~15% Zn utilization to achieve long cycle lives[1].

Technology Gap: Fundamental limitations of Zn batteries need to be addressed to achieve thousands of cycles.

APPROACH

State of the art: ZnO with additives, particularly $Ca(OH)_2$, is used to achieve hundreds of cycles.

Our approach: $Ca(OH)_2$ has been used for decades[2], but other alkaline earth metal additives are largely untested. Here we compare the influence $Mg(OH)_2$, $Sr(OH)_2$ and $Ca(OH)_2$ additives on ZnO anode performance in an alkaline system.

Lab capabilities: Sandia is well-suited for this type of research.

- Combined 250+ channels for battery cycling and electrochemical characterization.
- Computed Tomography (CT) capability to track shape change and formation of metallic agglomerates.
- Sandia-developed Cryo-FIB setup with a femtosecond laser for ablating large sections of material (>1 mm) for full electrode cross-section elemental analysis.

Experimental Setup:

- Pasted ZnO anode.
  - Bi_2O_3, and $X(OH)_2$ additives, where X is Ca, Mg, or Sr.
  - PTFE binder.
- Sintered Ni / $Ni(OH)_2$ cathode.
- Electrolyte is 20 wt.% KOH.
- Cycling protocol:
  - CC-CV charge (1.98V) to 30% anode Zn util.
  - CC discharge to 1.2V.

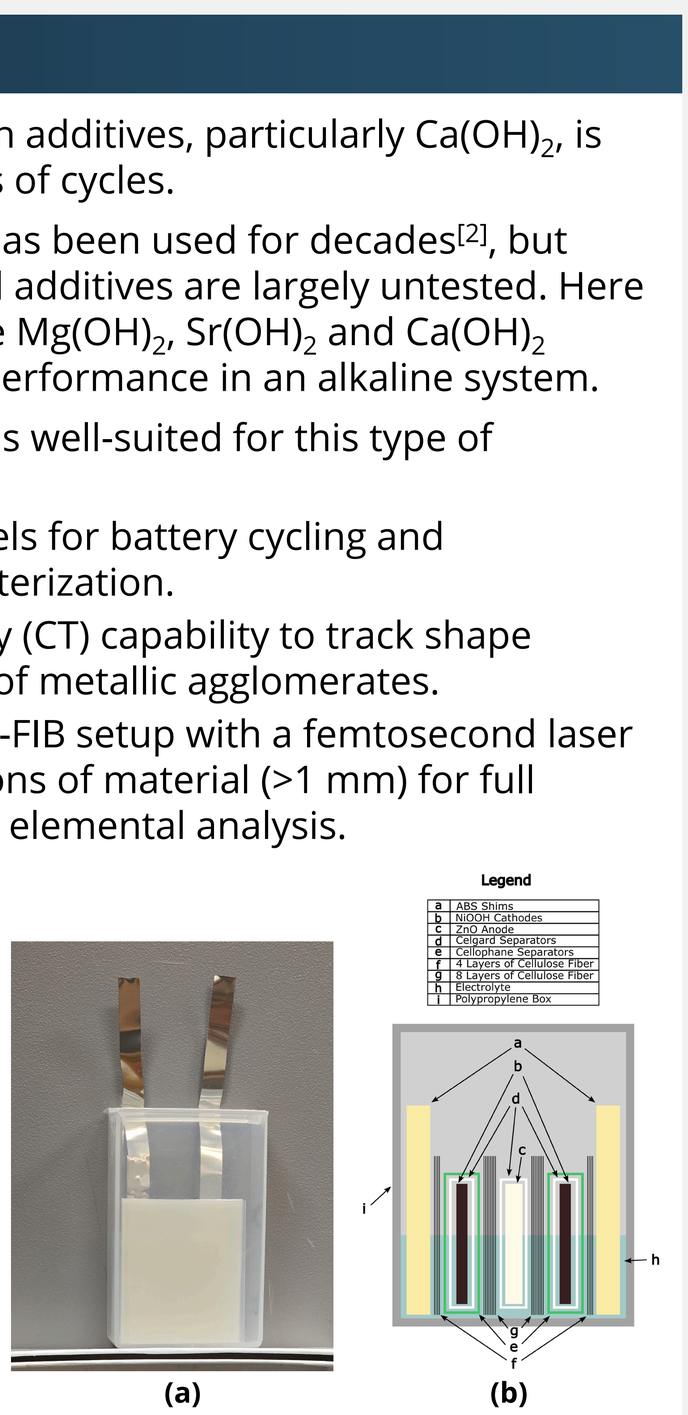

Fig. 1: *(a) Photo and (b) schematic of an assembled cell.*

RESULTS

Key Findings:

- Anodes with $Mg(OH)_2$ had 50-60% more capacity and 1.6x longer cycle lives.
- Anodes with $Mg(OH)_2$ have the lowest impedance (EIS).
- SEM/EDS shows that Mg, Ca, Sr separate from ZnO.
- Ca & Sr form carbonates (XRD) over time.
- FIB cross-sections reveal that electrodes with $Mg(OH)_2$ form large metallic Zn 'cores'.
- CT shows the Zn cores form at the center of electrodes.

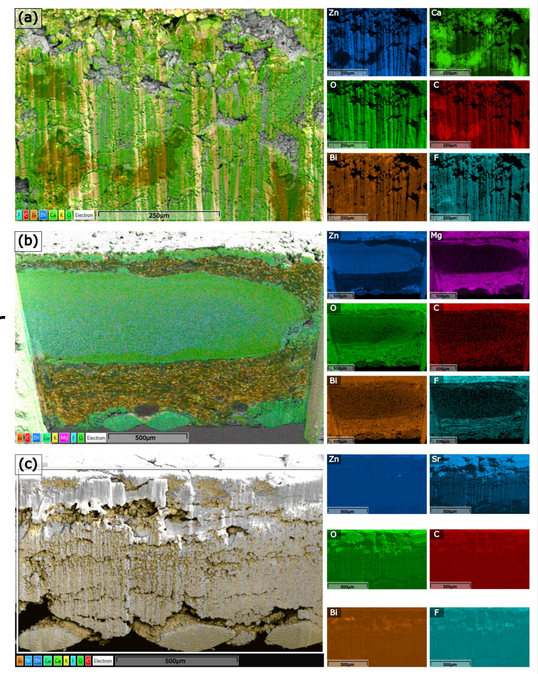

Fig. 2: *FIB-EDS analysis of cross-sections of an EOL anode stopped in discharged state with (a) calcium, (b) magnesium, and (c) strontium hydroxide additive.*

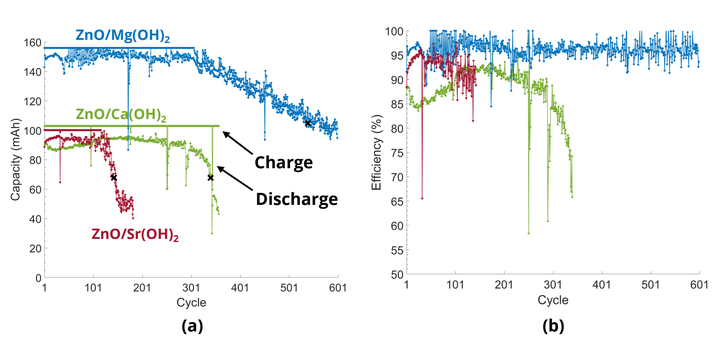

Fig. 3: *(a) Charge and discharge capacities and (b) Coulombic Efficiency vs. cycle number.* ***X*** *indicates EOL at 70% target capacity*

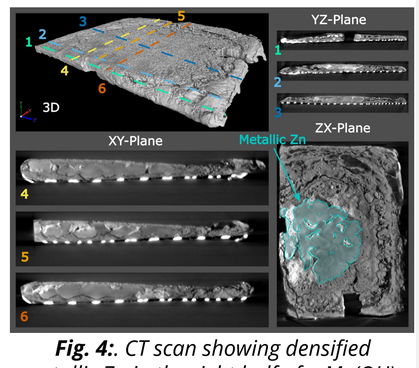

Fig. 4:*. CT scan showing densified metallic Zn in the right half of a $Mg(OH)_2$ electrode.*

CONCLUSIONS & IMPACT

- $Mg(OH)_2$ is a more favorable ZnO anode additive than $Ca(OH)_2$ based on delivered capacity and cycle life.
- Additives from the same group (alkaline earth metals) have a profound effect on the ZnO electrodes, which merits further study.
- This work[3] elevates the ZnO chemistry to higher volumetric capacity (~335 mAh cm^{-3}) with a longer cycle life (539).
  - This is an important step in developing the Zn system to be practical for energy storage use.
  - Anodes in the literature[4] achieve ~990 cycles at ~192 mAh cm^{-3} .

FUTURE DIRECTIONS

Next questions to answer:

- Can electrode/electrolyte modification further modify the electrodes microstructural evolution to increase cycle life?
- Can we further mitigate or prevent dendrite formation?
- Can parasitic side reactions (HER, OER, etc.) be reduced?
- Can utilized capacity be higher (≥50%) in alkaline?

References

[1] M.J. D'Ambrose et al., 2023. *ACS Appl. Energy Mater*., 6(11), 6091-6103.
[2] E.G. Gagnon and Y.M. Wang, 1987. *J. Electrochem. Soc*. 134(9), 2091-2096.
[3] I.I. Bezsonov et al., 2026. *Manuscript in preparation*.
[4] D.E. Turney et al., 2017. *Chemistry of Materials* 29(11), 4819-4832.

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