National Aeronautics and Space Administration

FY23 Topic Areas Research and Technology Development (TRTD)

Expanding the Operation Temperature Window of Zinc Metal Anode Batteries for Applications under Extreme Conditions in Space Missions

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Strategic Focus Area: Energy storage

Objective:

Develop a new and safe rechargeable battery chemistry

- Develop Zn metal batteries with specific capacity ≥250 mAh/g (cathode-basis), cycle life > 500 at room temperature
- Featuring a non-flammable electrolyte with a with temperature window range of of -40 °C to 90 °C

Background:

The battery safety and operation temperature window are of particular interest as battery cells become more energetic. Unfortunately, lithium-ion batteries (LIBs) are intrinsically unsafe due to the use of flammable electrolytes posing risk to critical missions. Aqueous rechargeable zinc metal anode batteries, however, are free of the thermal runaway problem due to the use of water as the electrolyte. They have received increasing attention owing to their relatively high energy density and safety. In addition, the zinc metal anode has better intrinsic performance at temperatures below -20 °C compared to the graphite anode used in lithium-ion batteries.

Approach and Result

- Non-flammable electrolyte development for improved performances at low and high temperature (0 °C and 50 °C).

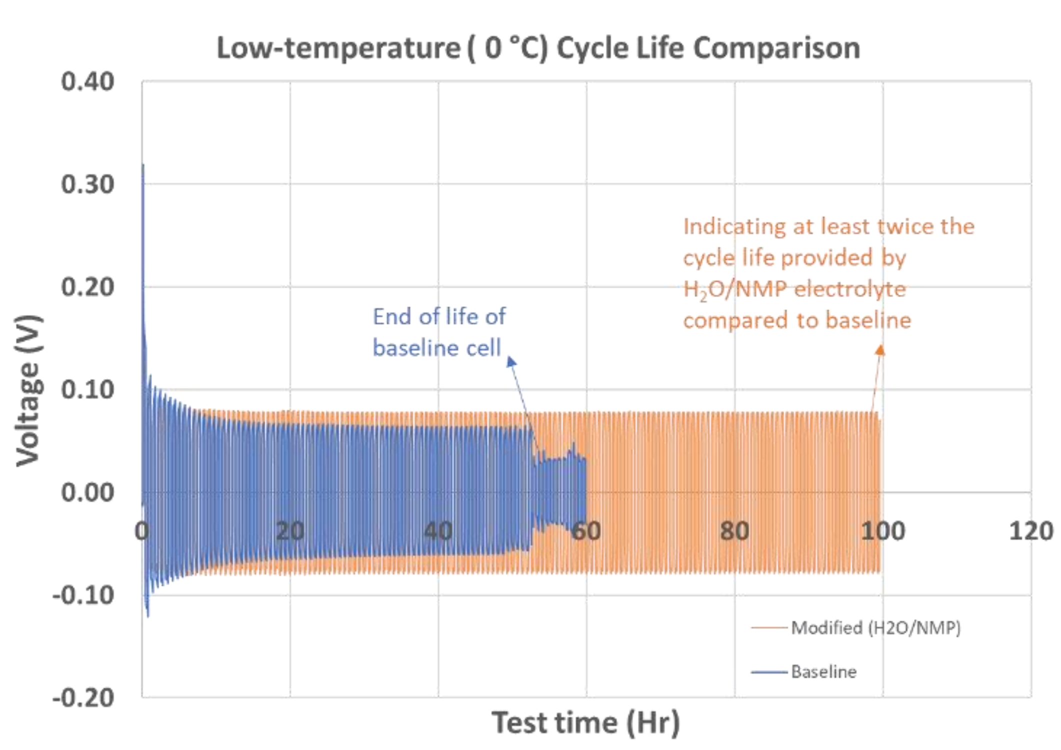

Figure 1. Comparison of cycle life between H_2O/NMP-based electrolyte and baseline aqueous electrolyte.

- An promising non-flammable Zn-ion electrolyte with melting point at approximately -60 °C, which is composed of 2 M zinc trifluoromethanesulfonate ($Zn(OTf)_2$) and 0.5M 1-butyl-3-methylimidazolium trifluoromethanesulfonate ([BMIm]OTf) in H_2O.

Approach and Result

- The preliminary characterization results indicated that the surface roughness of Zn electrode at the Zn/electrolyte interface has profound influence on the Zn deposition microstructure.

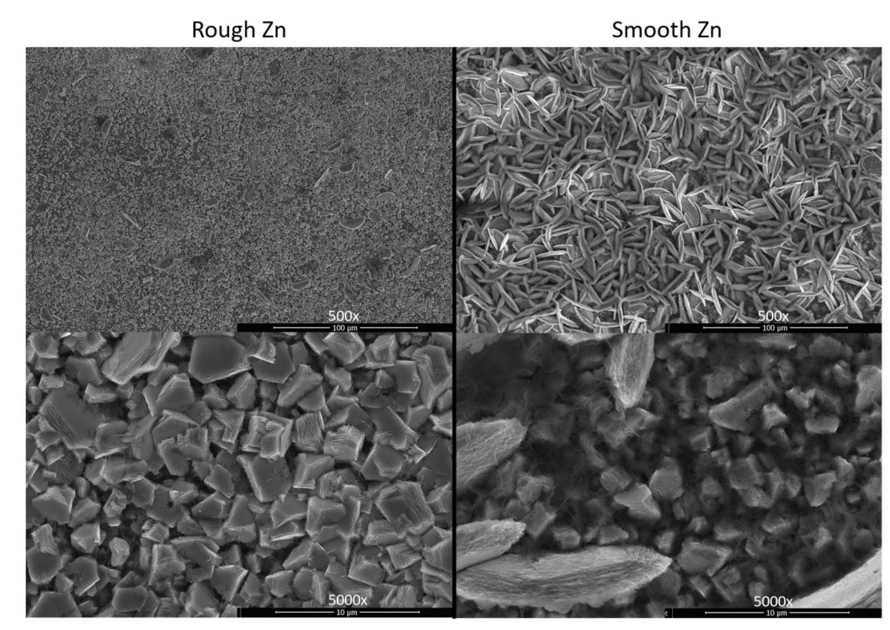

Figure 2. SEM images of Zn deposition on the roughed surface vs. on the smooth surface; the deposition capacity is 1.5 mAh cm^{-2}

- α-MnO_2 was prepared by a solution-based reaction between $KMnO_4$ and $MnSO_4 \cdot H_2O$. Nanoparticles of carbon black was incorporated in the reaction resulting to an α-MnO_2-C composite.

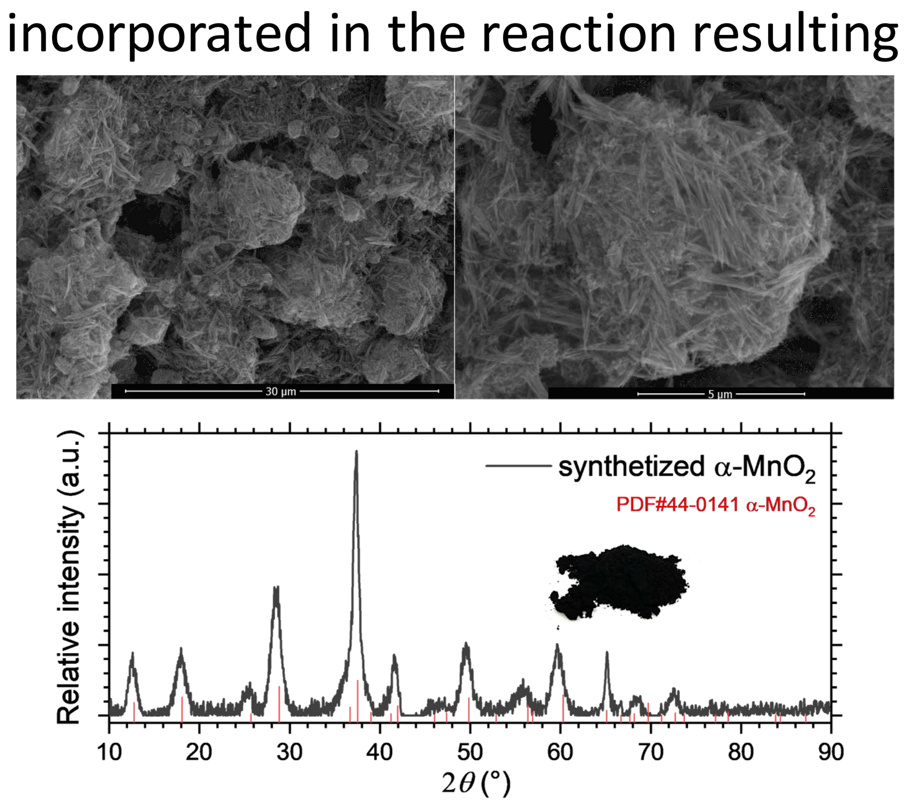

Figure 3. *SEM images and XRD pattern of the* α-MnO_2*-C particles.*

- A full rechargeable Zn-ion battery using the $Zn(OTf)_2$/[BMIm]OTf/H_2O electrolyte with alpha manganese oxide (α-MnO_2) cathode and Zn anode is demonstrated.

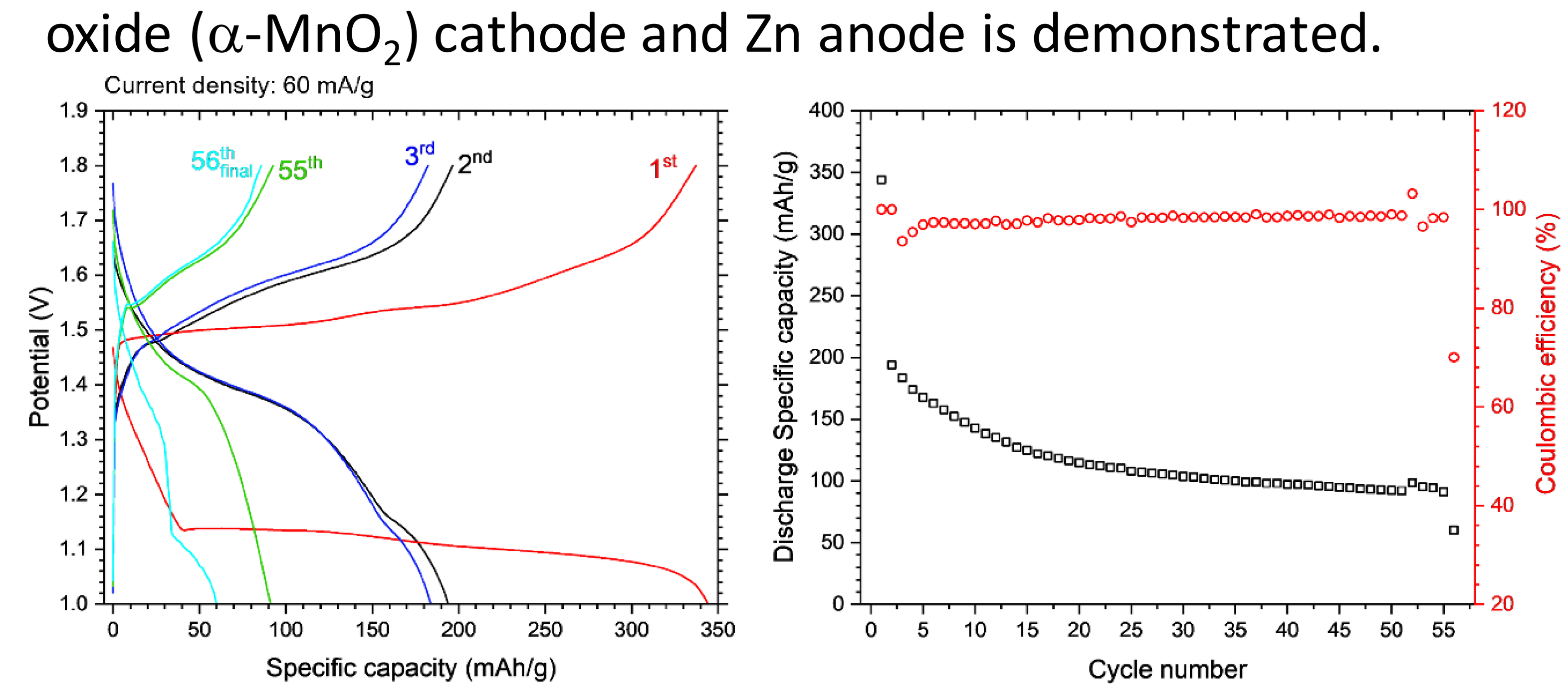

Figure 4. *Representative cycling charge-discharge curves of Zn-*MnO_2 *cells and cycle stability plot.*

Significance/Benefits to JPL and NASA:

Developing high specific energy, high power, safe batteries is of crucial importance for reducing the payload mass and improving the reliability of future power systems for NASA's space missions. Due to the divalent nature of zinc, zinc metal anodes have extremely high gravimetric and volumetric specific capacities (5,855 mAh cm^{-3} and 820 mAh g^{-1}) which are more than twice that of graphite anodes used in LIBs. Moreover, the zinc metal battery could potentially greatly expand the operation temperature window. Below -30 °C, Li insertion in the LIB anode would become limiting due to the interphase shutdown. This problem cannot be solved by tuning the electrolyte alone, however zinc metal battery with a new battery chemistry can potentially solve this problem.

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Clearance Number: CL#00-0000
Poster Number: RPC-199

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