Engineering Zn and Mn Anodes for Aqueous Batteries

Nian Liu

Associate Professor

School of Chemical and Biomolecular Engineering

Georgia Institute of Technology

nian.liu@chbe.gatech.edu

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Project Overview

- Project Goal: We aim to develop low-cost, high-energy batteries by using manganese and zinc metal electrodes in non-flammable water-based electrolytes.
- Current Practice: Today's metal-based batteries pair manganese oxide with zinc but suffer from short cycle life, high cost, and limited specific energy.
- Why Georgia Tech: Expertise on aqueous batteries, cutting-edge materials labs, and strong partnerships with DOE national labs and user facilities.
- Innovation: We will create novel metal electrode designs and customize the battery electrolyte to stop material loss and extend battery life.
- Impact: Success will yield affordable, durable batteries for backup power and grid storage that rely on abundant, non-critical materials.
- Alignment: This work directly supports DOE Office of Electricity goals by advancing long-duration, resilient energy storage for a flexible and reliable power grid.

Project Team

Zhitao Chen

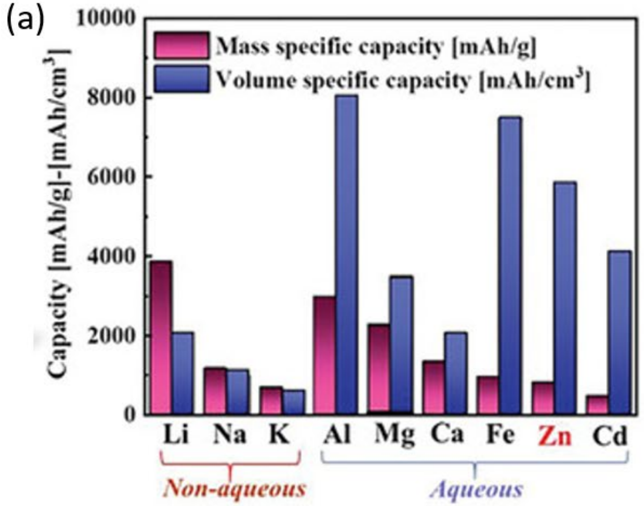
Dr. Timothy N. Lambert
Sandia

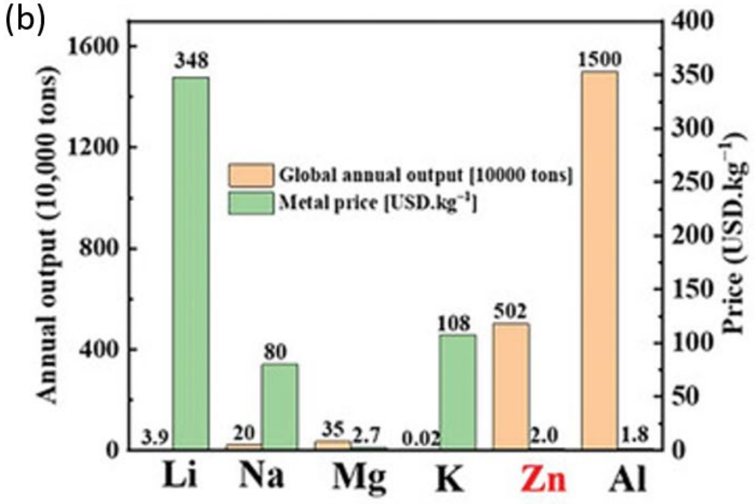
Dr. Jason Huang
Sandia

Dr. Calvin D. Quilty
Sandia

Dr. John Watt
CINT

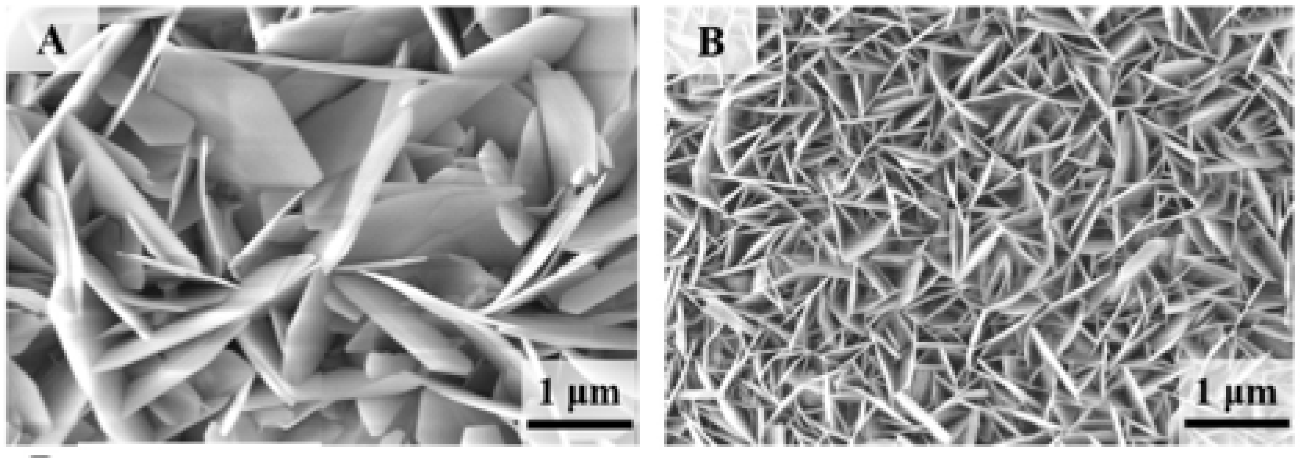
Zinc metal anode in neutral/mild acidic





Small **16**, 2000730-2000758 (2020)

Electrodeposition morphology of zinc



ACS Appl Mater Inter **13**, 32930-32936 (2021)

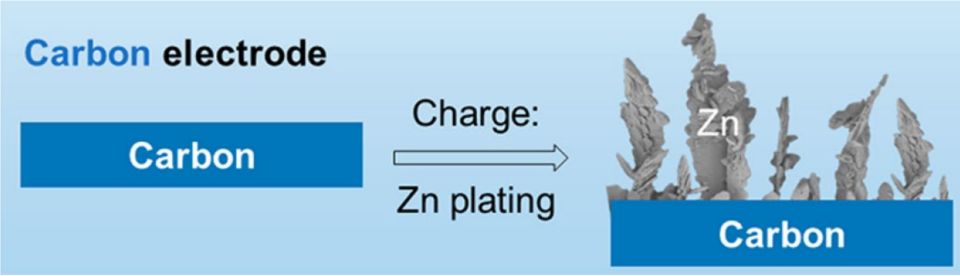
Metallic zinc anode

- **High theoretical specific capacity (820 mAh/g, 5854 mAh/cm^3)**
- **Aqueous electrolyte**
- **Low redox potential**
- **Low cost**
- **Dendrite formation**
- **Parasitic reactions**

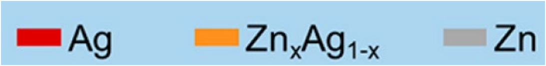
Existing effort

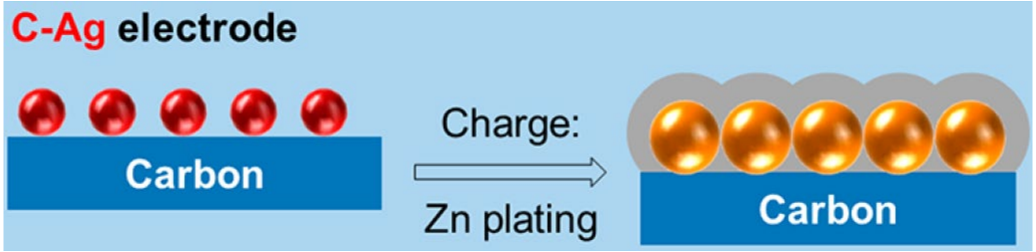
- Electrolyte additives
- Zn electrode coating including CNT coating, graphene coating, ion-sieving carbon nano shells
- Zn electrode additives including Bi, In, Pb

Soluble zincate: Passive encapsulation →Active management

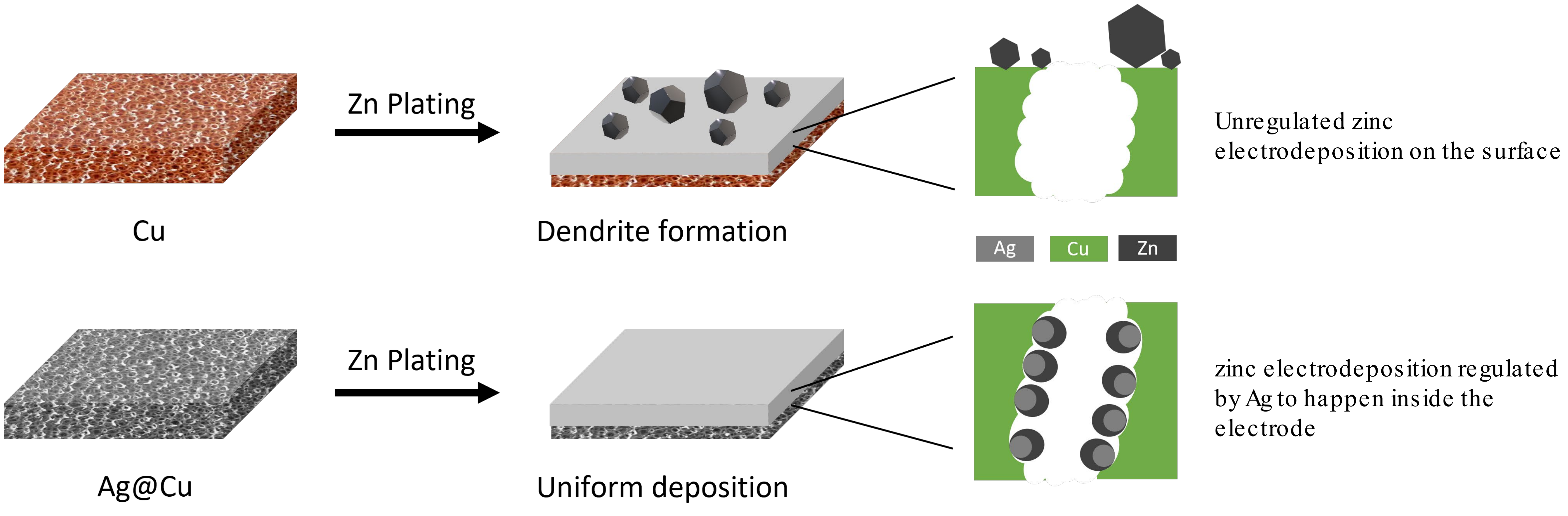


Y. Zhang, N. Liu* et al.
ACS Energy Lett.
2021, 6 (2), 404–412





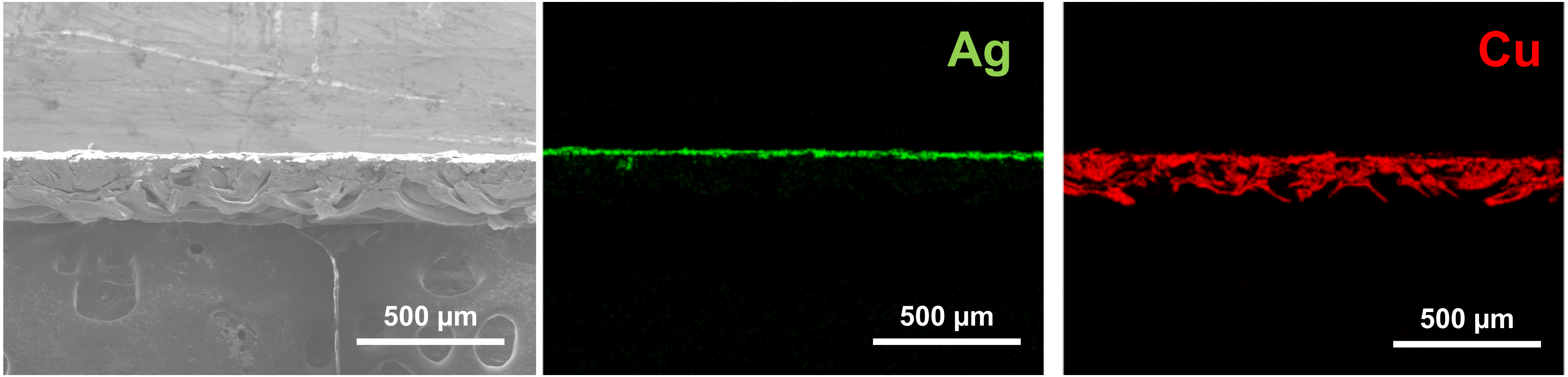
Alloy Seeded Host (ASH) Zinc Anode



3D structure-zinc electrodeposition throughout the electrode in neutral electrolyte

- Alloy seeded host (ASH) Zn anodes have a conductive host material such as super P carbon, that is decorated with zinc-alloying metal, Ag, as seed on the 3D substrate, Cu foam.
- The host accommodates the zinc during electrodeposition process, and the Ag decoration spatially controls the zinc deposition to happen inside the host to achieve uniform and dendrite-free zinc electrodeposition in a 3D structure.

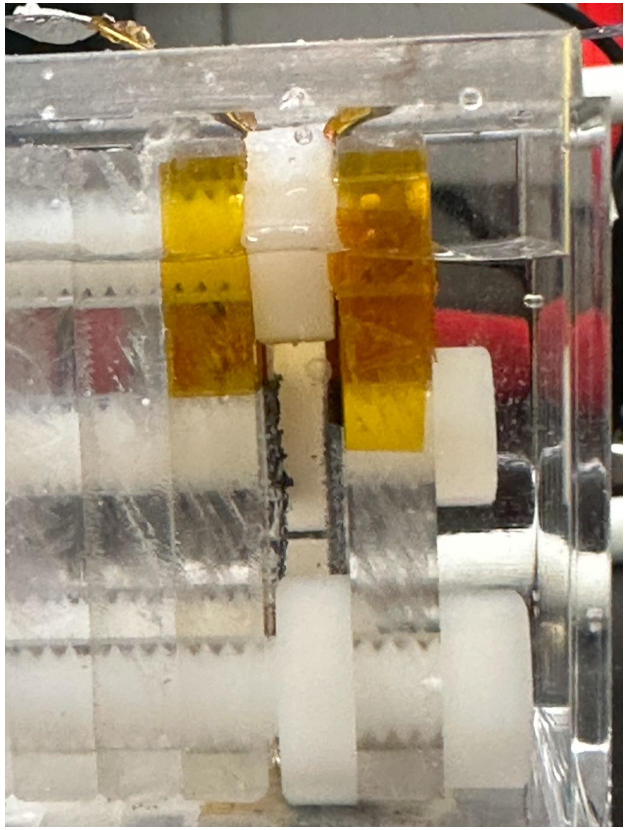
Ag decorated Cu foam

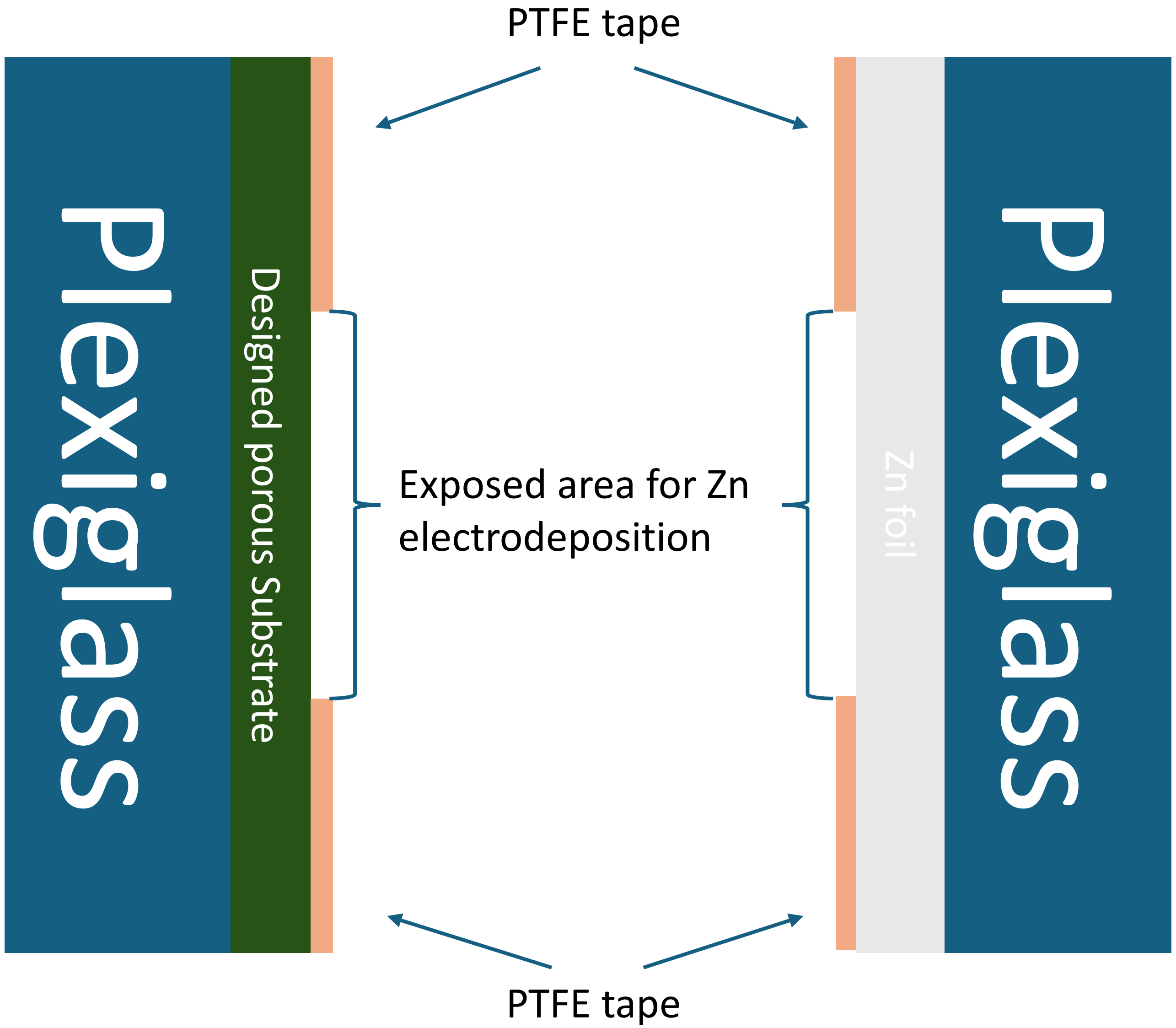


Ag decorated Cu foam

- Ag-rich side is created by using Ag sputtering
- Cu-rich side will be placed facing towards Zn foil counter electrode
- Zn will preferentially deposit on Ag-rich side and fill the porous structure of Cu foam
    - Zn deposition preference (Ag>Zn>Cu)
- This can realize ultrahigh Zn mass loading and areal capacity

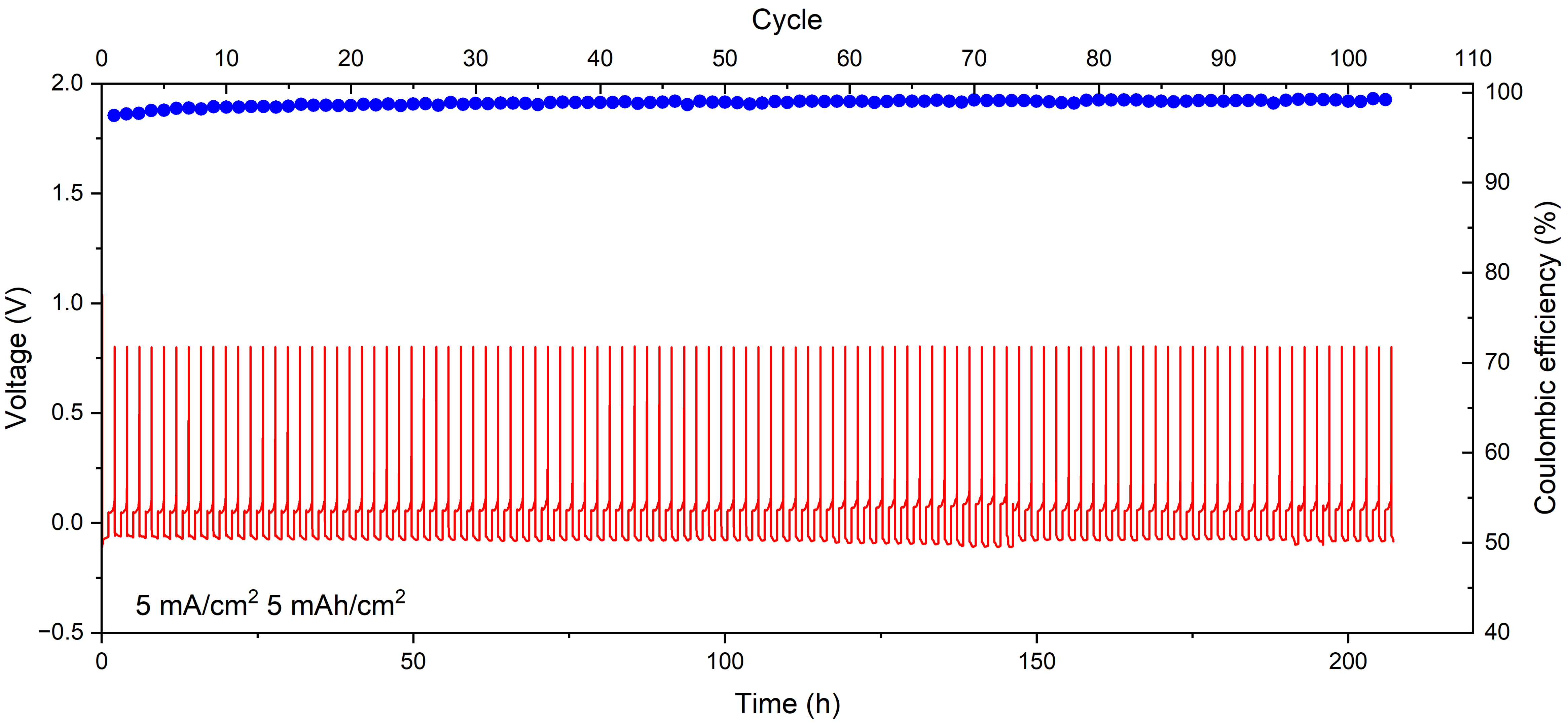
Configuration of beaker-type cell



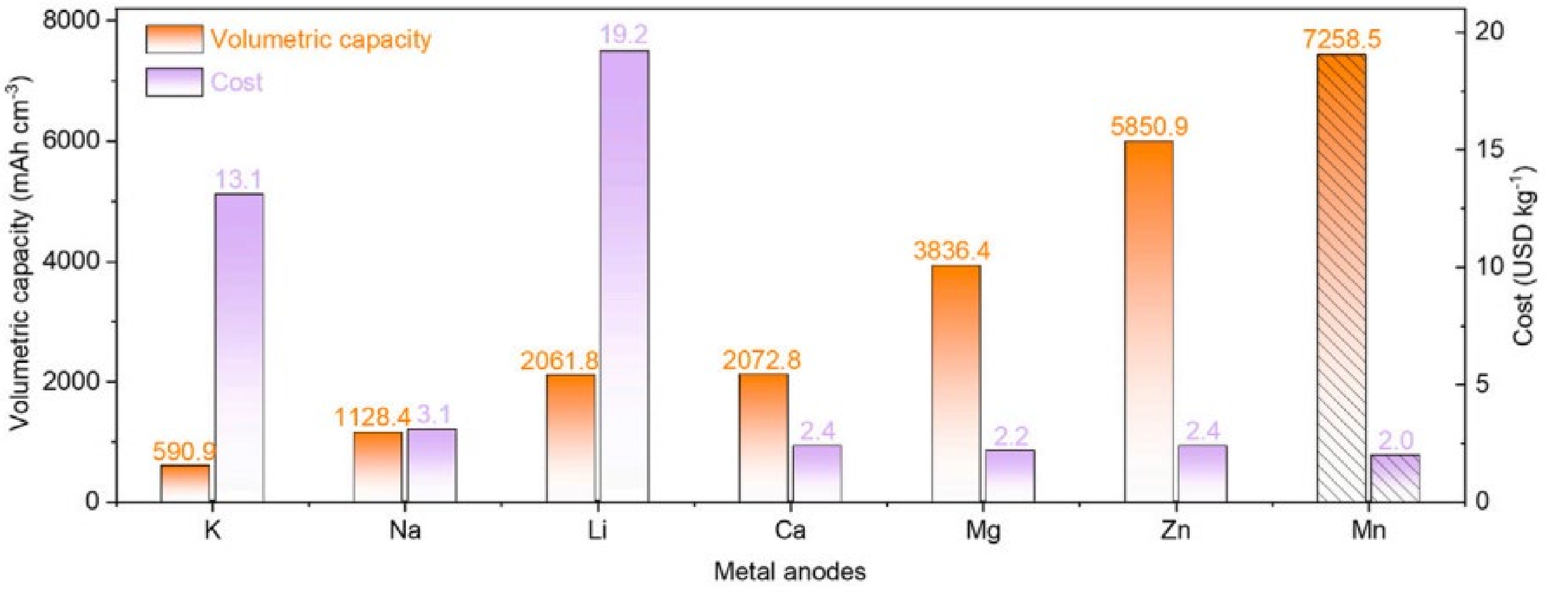


The battery will be vacuum soaked for 1 h and then rest for 2 h before testing

Cycling performance



Overview of Mn anode



Joule, 8(3), 583–598

- Mn anode has highest volumetric capacity but lowest cost, exceling all the elements listed in the table
- The redox potential is even lower than Zn, leading to higher discharge voltage

However,

- Mn anode suffers from hydrogen evolution reaction
- The main problem is the reversibility of plating/stripping reactions of Mn/Mn^{2+} on Mn anode

Electrolyte design strategy

- Design strategy scheme
- Low water activity
  Using potassium acetate (KAc) and sucrose to alter the solution structure
- pH-control Balance between Solubility of $Mn(OH)_2$
  ↕
  Mn reduction potential Vs. HER

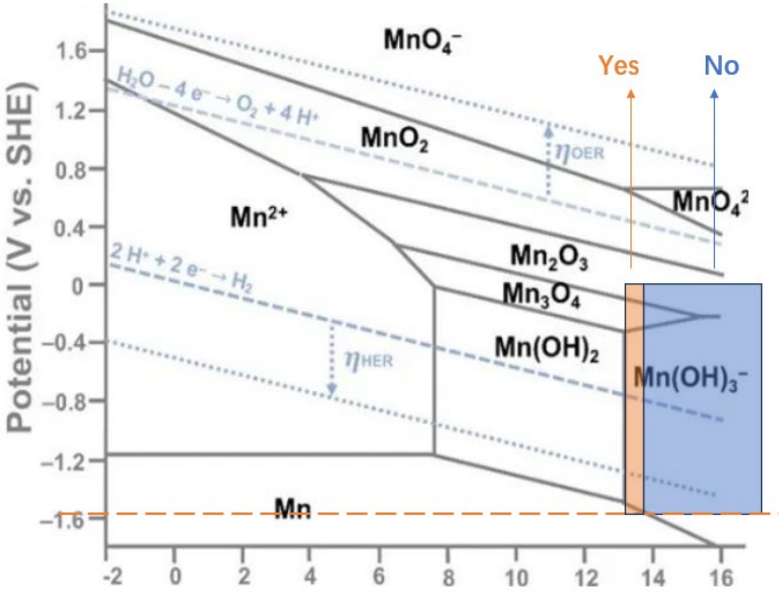
Water activity

- KAc + sucrose

Adding different concentration of KOH

pH-control

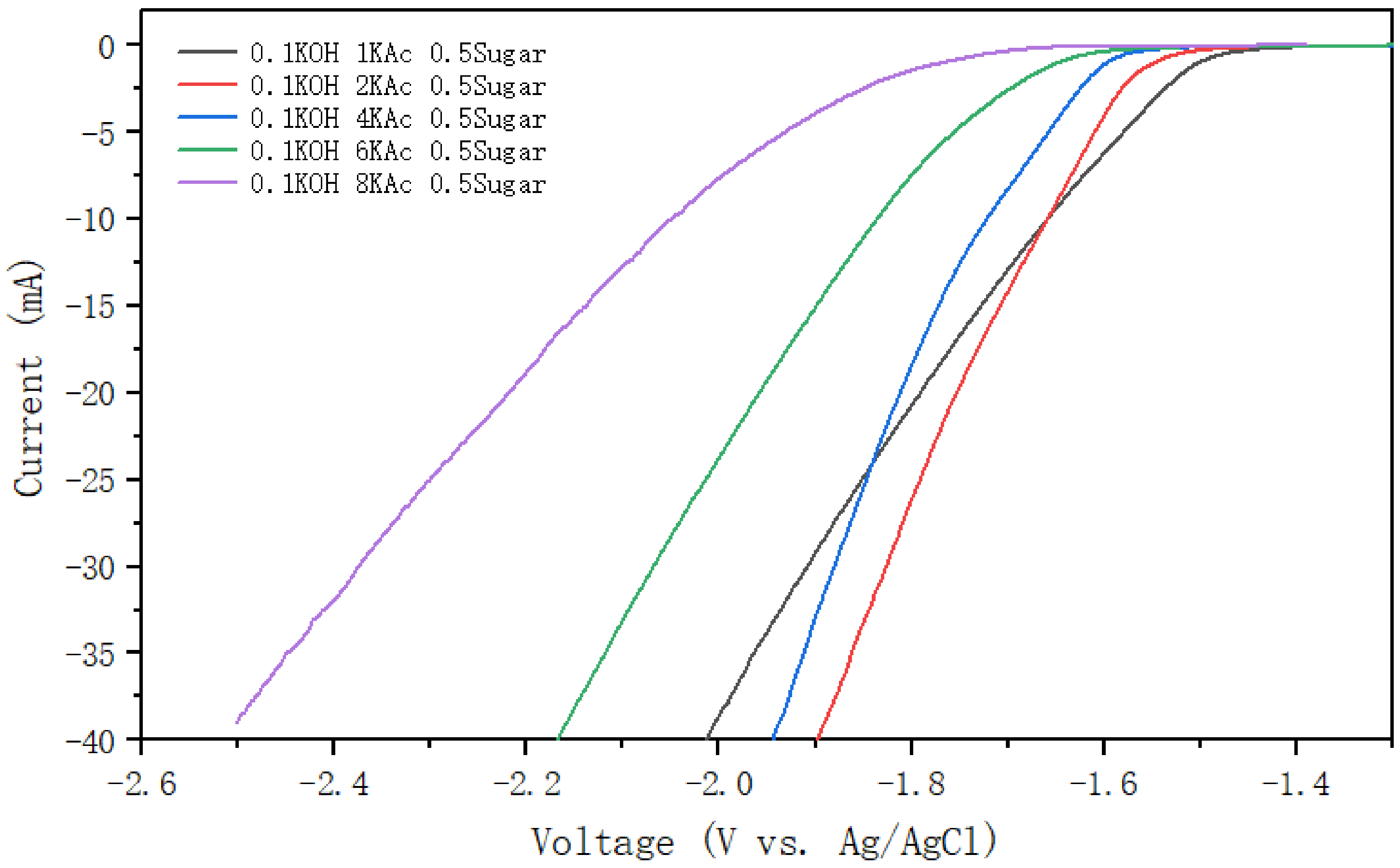
- **KAc + Sucrose + KOH**

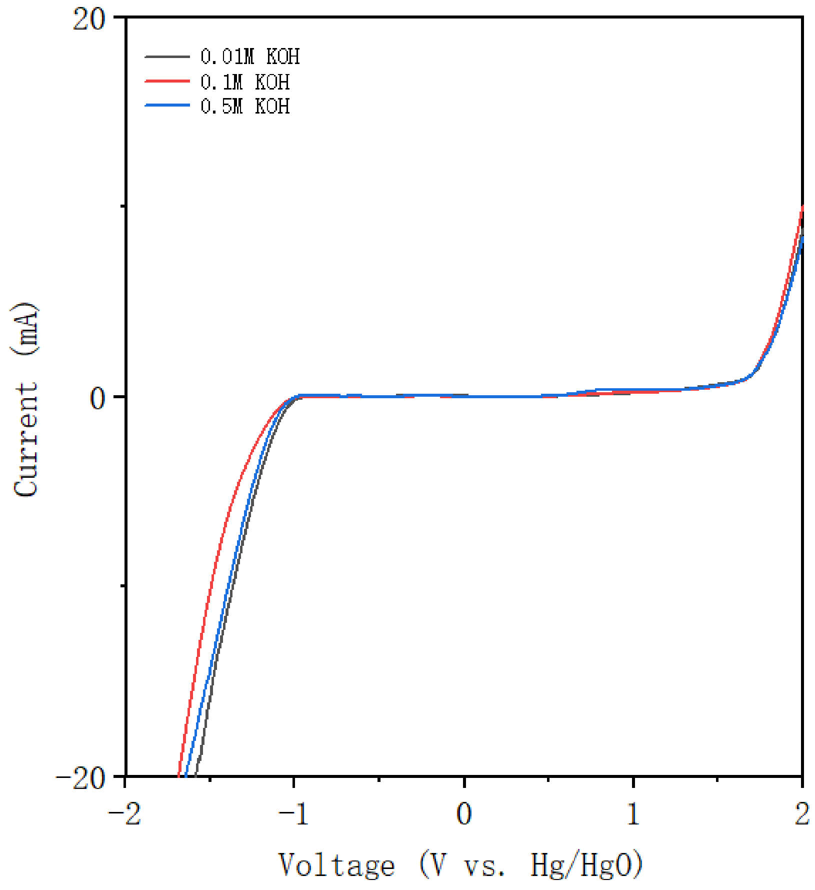


We will test the electrolyte in four main aspects

- Electrochemical window
- Ionic conductivity
- Solvation structure
- Compatibility with Mn anode

Potential window





- Potential window of electrolyte with same concentration of KOH and sucrose but different KAc concentrations
- It can be clearly seen that the potential window is widen in the electrolyte with 0.1M KOH + 8M Kac + 0.5M sucrose and suppress HER

- 0.1M KOH demonstrates widest potential window compared to other concentrations

Compatibility between electrolyte and Mn anode

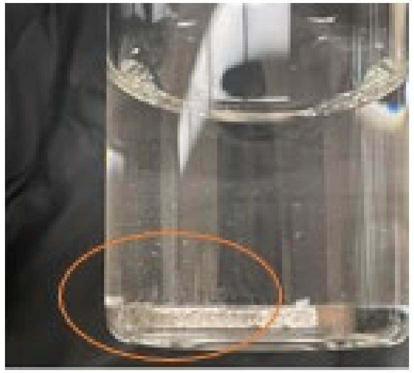
0.05M

0.1M

0.3M

0.5M

1M

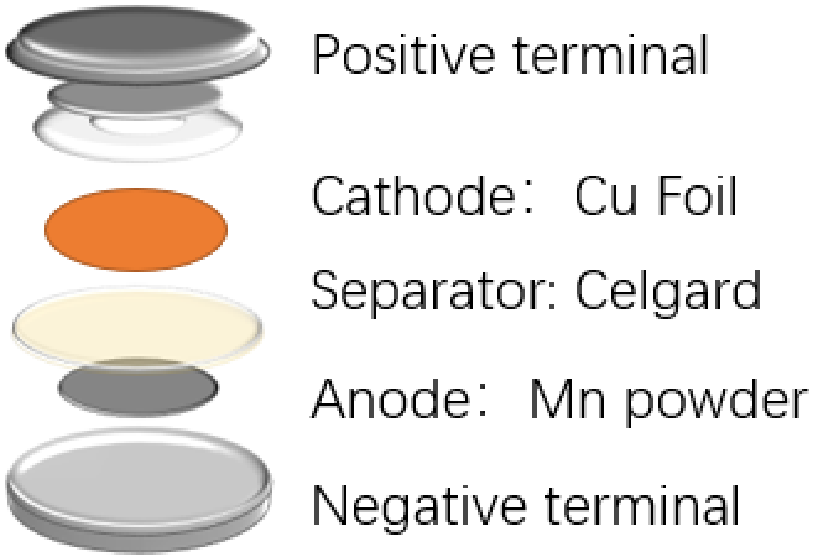


4M

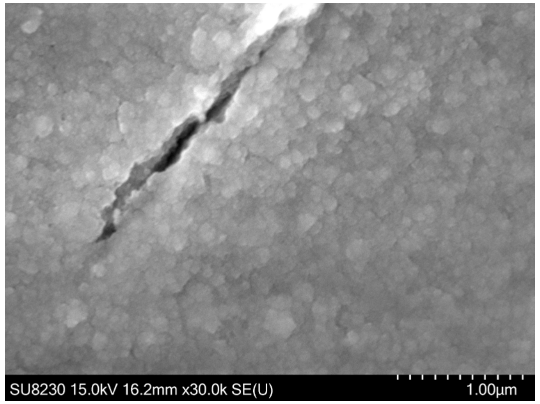
Base electrolyte: 8M Kac + 0.5M sucrose

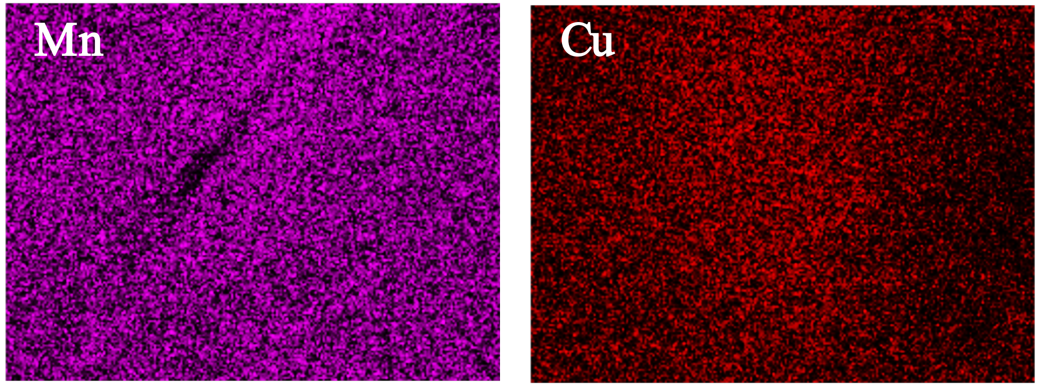
- **Experimental result**
  - **A small Mn plate is placed in electrolyte with different concentration of KOH**
  - **There is bubble formation in the electrolyte with KOH concentration higher than 1M**

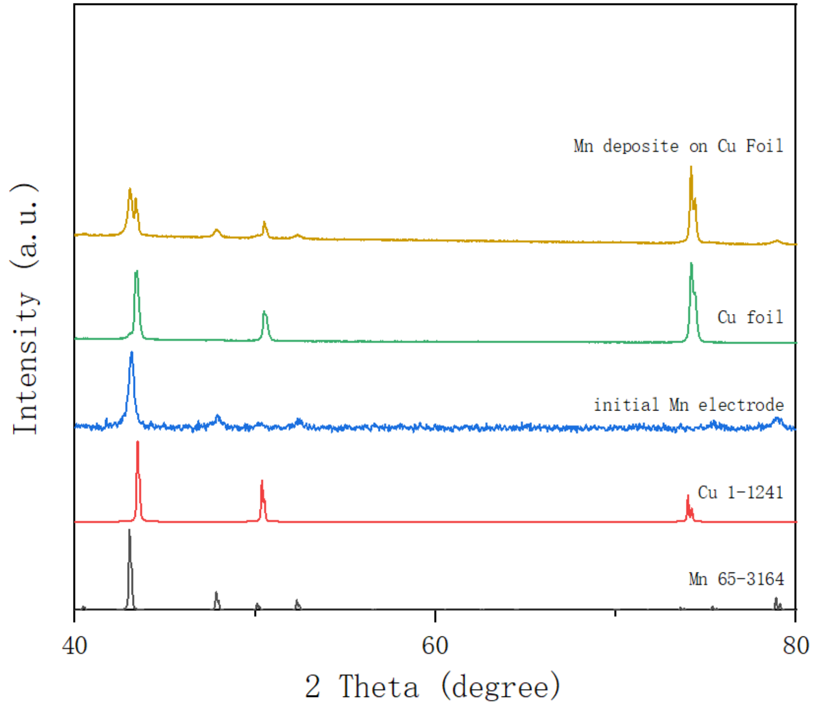
Mn deposition in Mn-Cu coin cell



- Electrolyte- 0.1M KOH, 8M KAc, 0.5M sugar with sat $MnCl_2$)
- 0.1mA/cm^2, 0.01mA/cm^2







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