Material Engineering of Anodes for **Aqueous** Batteries with Enhanced Performance for Aerospace Applications

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Lithium Battery Air Incidents

involving smoke, fire, or extreme heat

Federal Aviation Administration

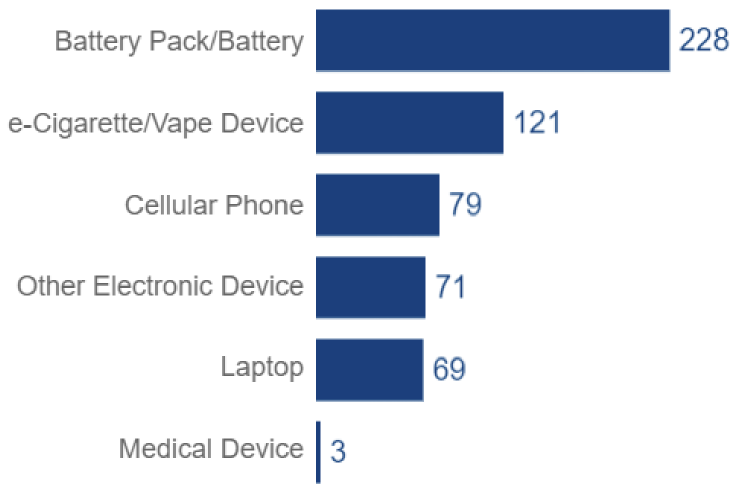
Click on any metric or the line icon to filter charts

Click to reset filters

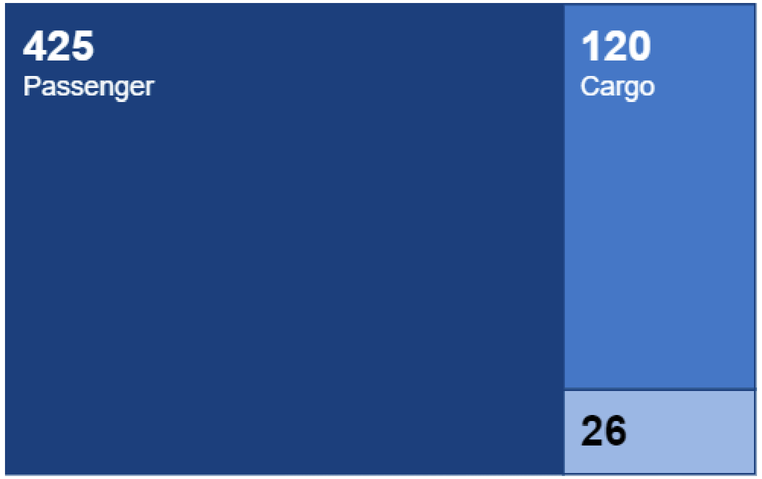
571
Total Verified Incidents
between 03-Mar-06 and 13-Oct-24

61
Year-to-Date Verified Incidents
Through November 15, 2024

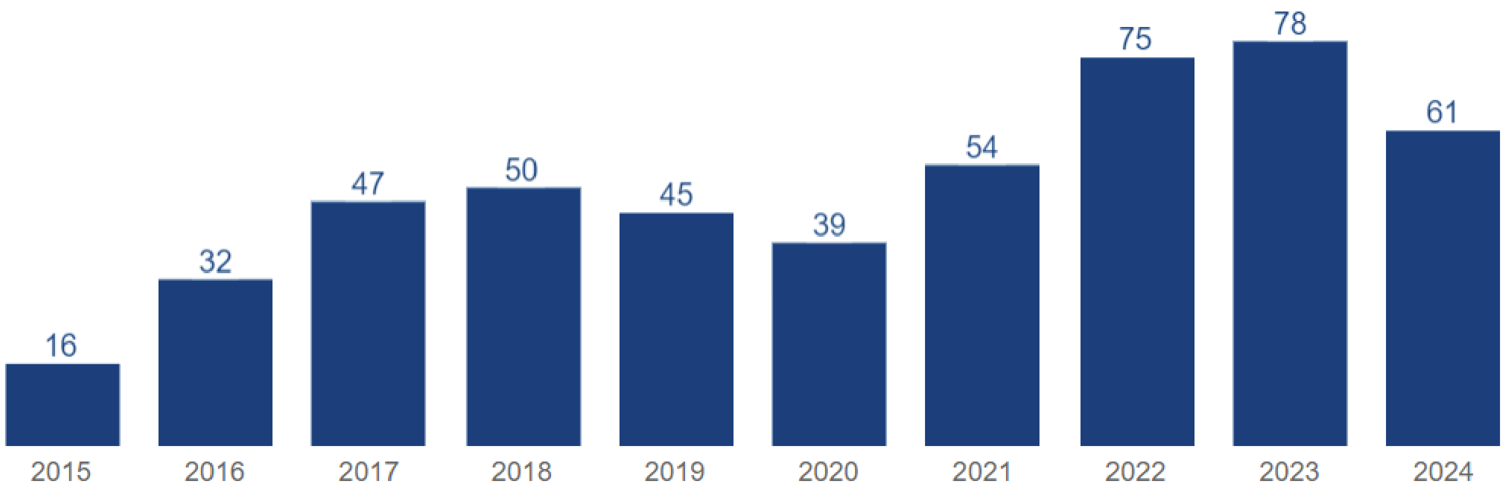
Category



Carrier Type



Lithium Battery Incidents (Past 10 Years)



Source: Federal Aviation Administration, Security and Hazardous Materials Safety

Last updated November 15, 2024

Revisiting pre-Li technologies that are intrinsically safer (all aqueous)

- Nickel metal hydride (NiMH) batteries have been used in space applications, including the Horyu-4 satellite and the NOZOMI mission:
  NOZOMI: The first mission to use NiMH cells in space, launched in 1998
  Horyu-4: Used NiMH batteries in its design
- Silver-zinc batteries are often used in space applications because they are lightweight, compact (1/3 the size of NiCd batteries), and powerful:
  The first battery used in space was a silver-zinc battery in the Russian spacecraft Sputnik in 1957.
- Enhance their rechargeability and utilization
- Mars surface T varies from -153°C to 20°C
  Moon surface T varies from -246°C to 127°C

Part I

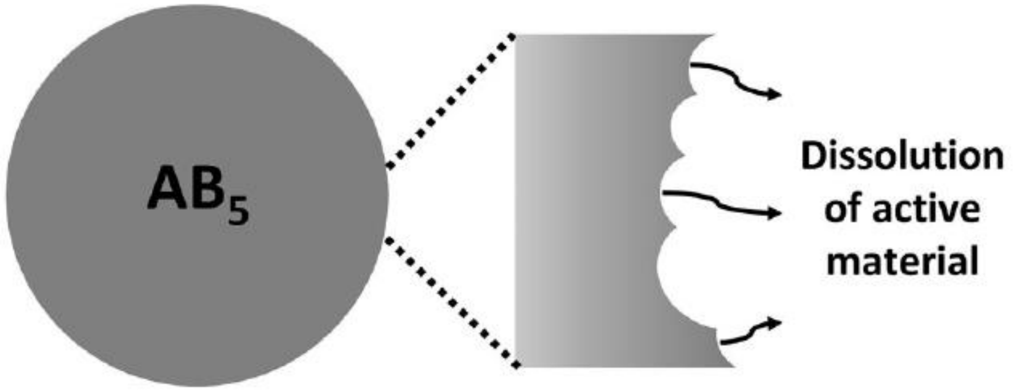
Enhancing the rechargeability of high-power nickel metal hydride anode

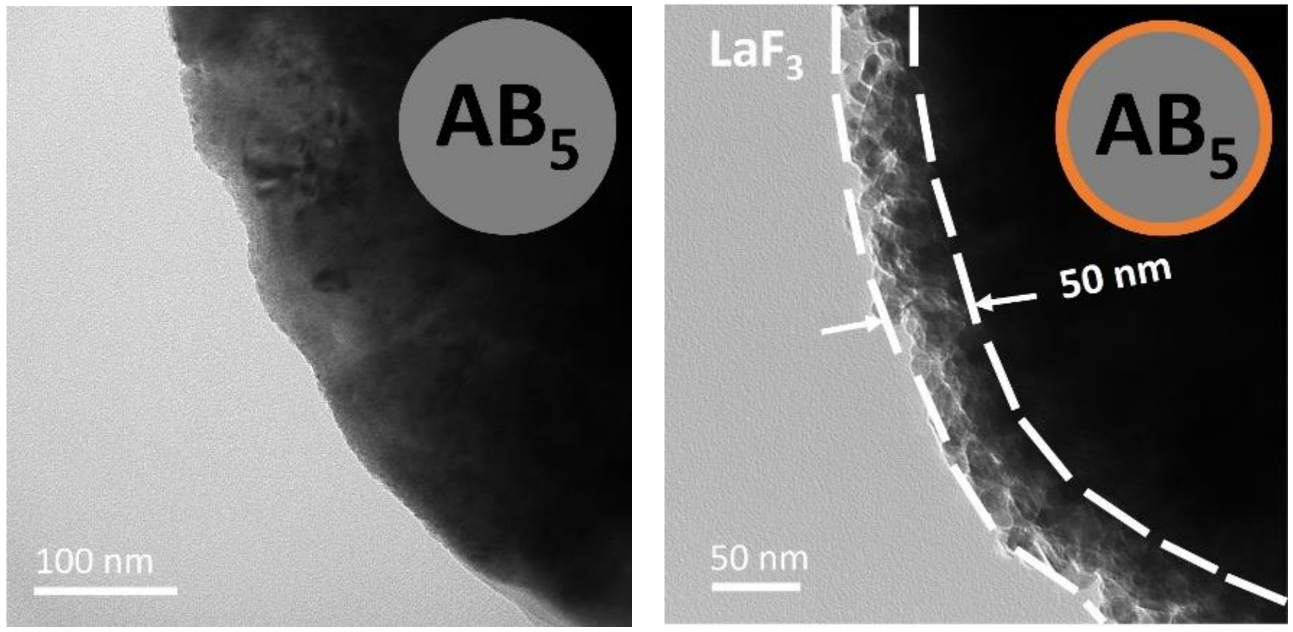
Part II

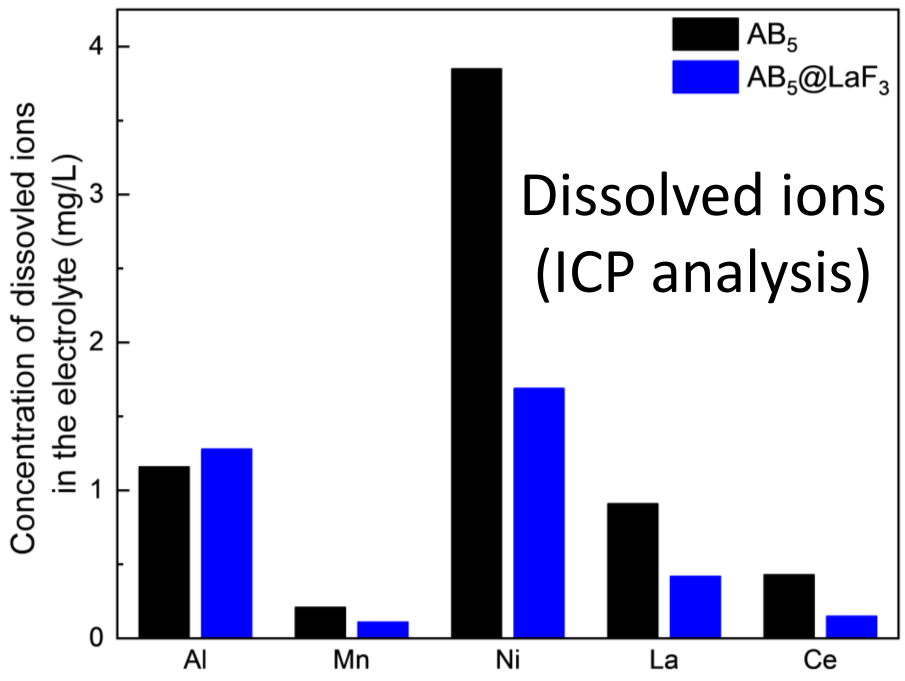
Enhancing the rechargeability and utilization of zinc anode

Stable cycling of NiMH battery anode via surface coating

AB_5-type hydrogen storage alloy: $La_{9.2}Ce_{6.0}Pr_{0.2}Nd_{0.7}Zr_{0.3}Ni_{73.0}Mn_{5.9}Al_{4.6}$ (excellent low-T rate capability)

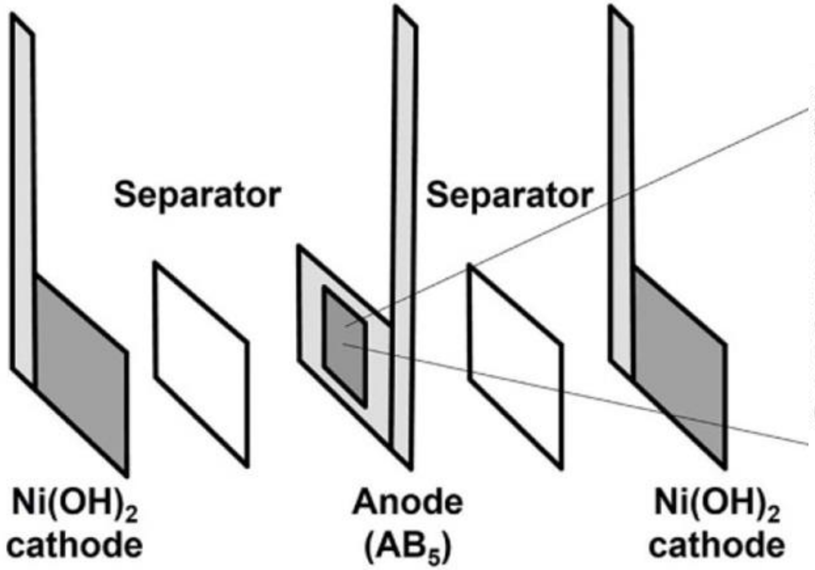


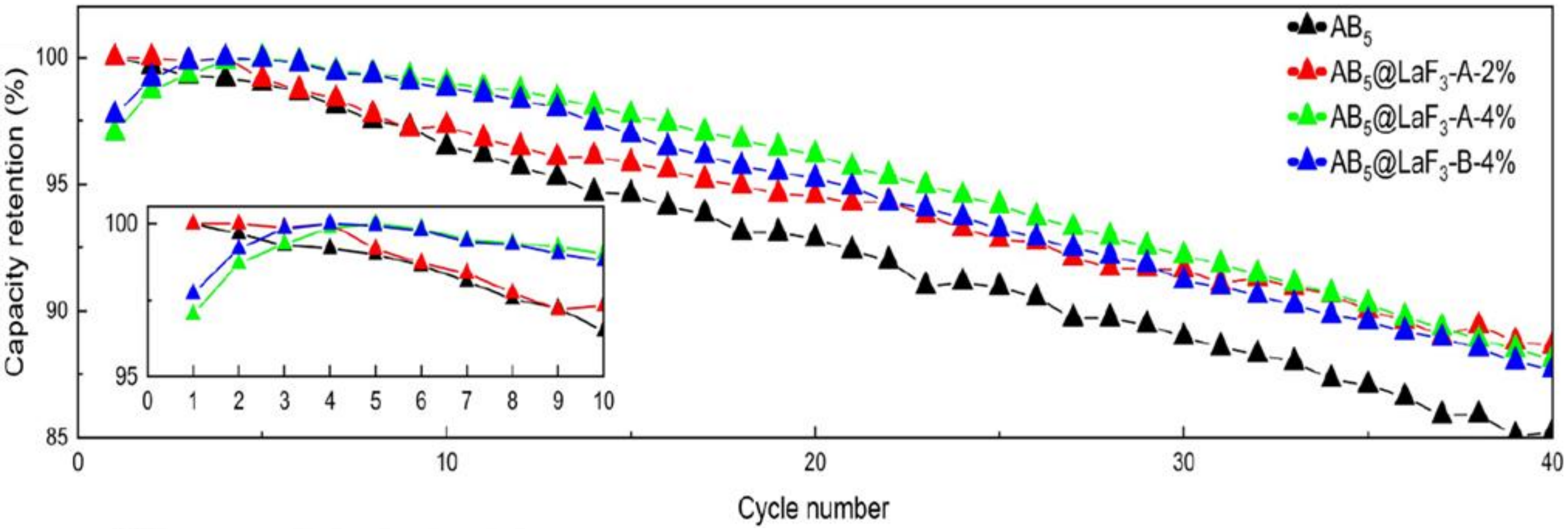


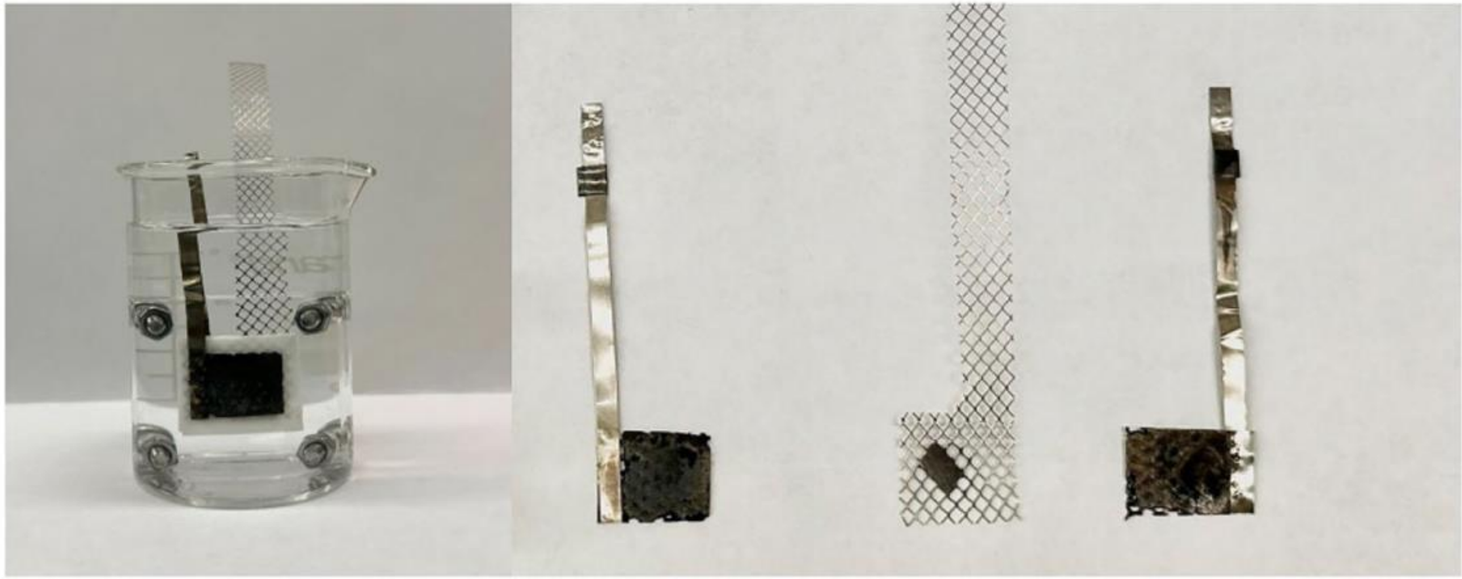


Z. Chen, H. Liu, J. Nei, N. Liu*, ***Nano Research*** 2024, 17, 8819–8825

Stable cycling of NiMH battery anode via surface coating

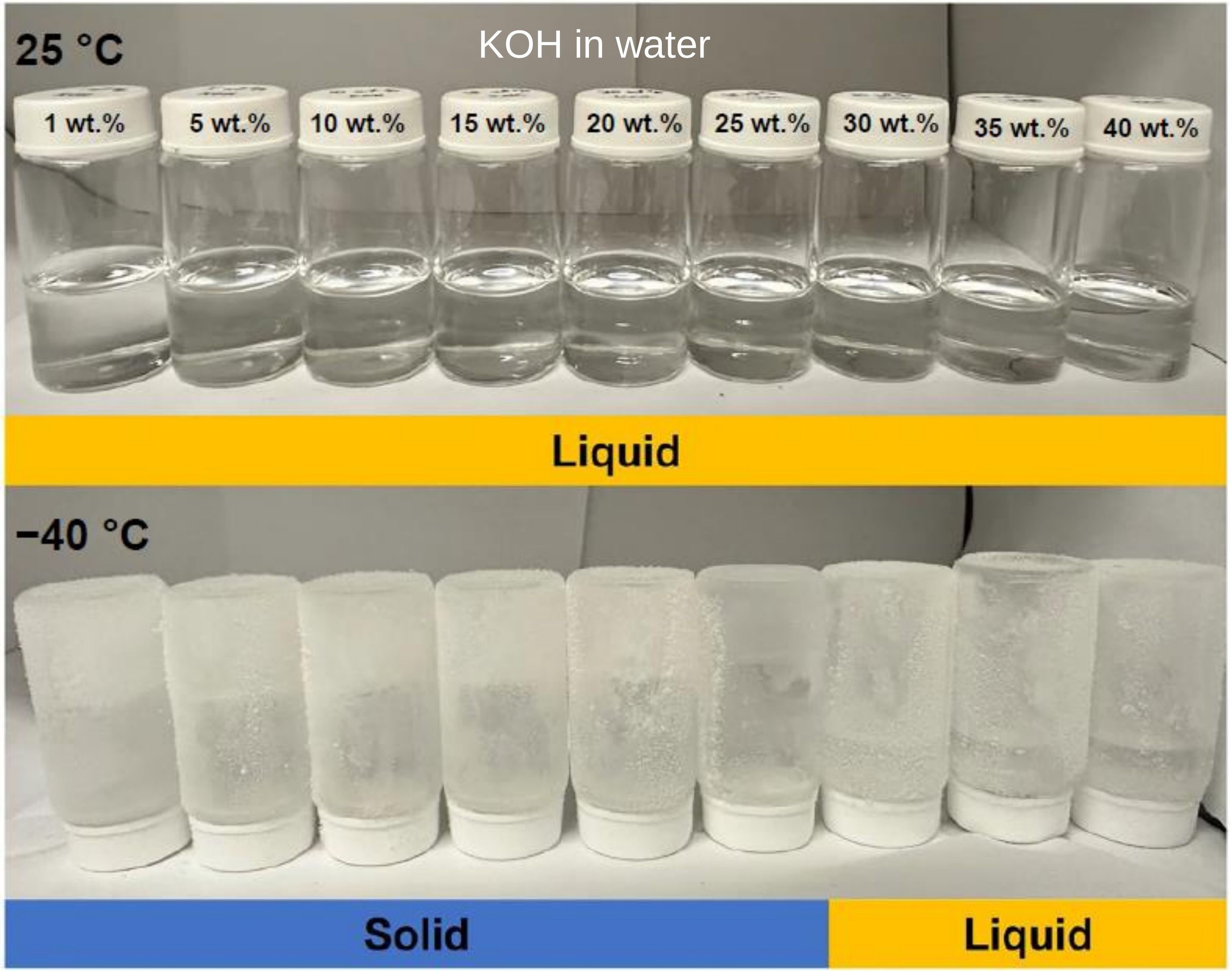


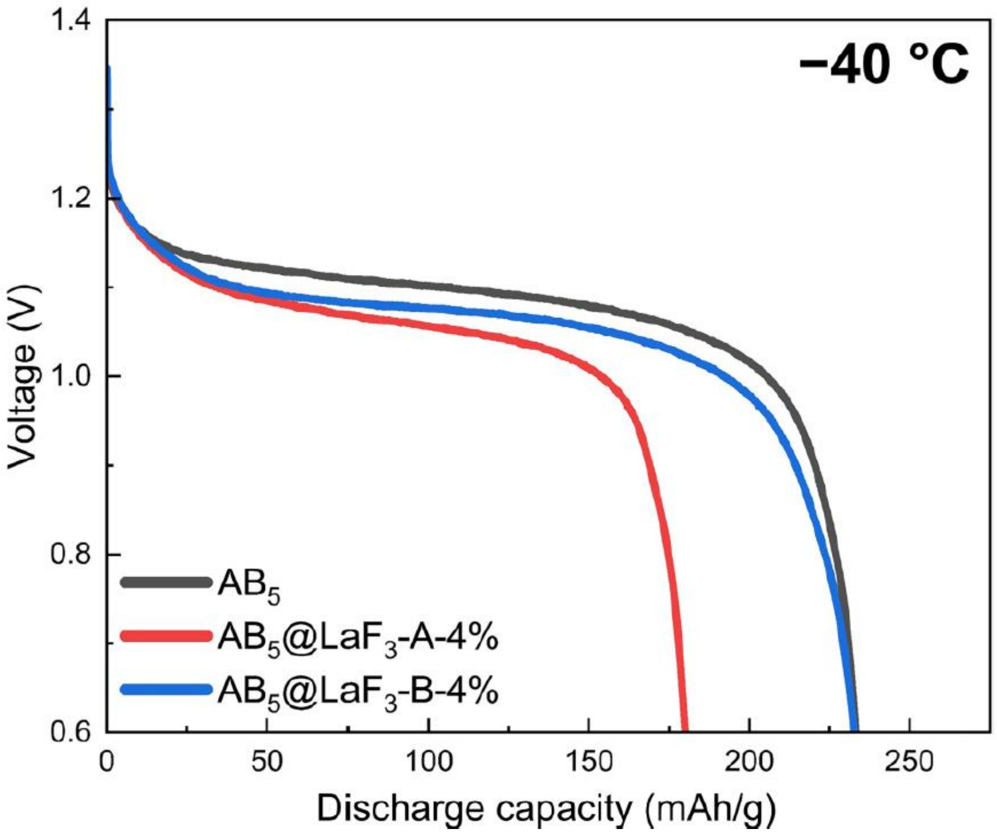




Z. Chen, H. Liu, J. Nei, N. Liu*, ***Nano Research*** 2024, 17, 8819–8825

Stable cycling of NiMH battery anode via surface coating



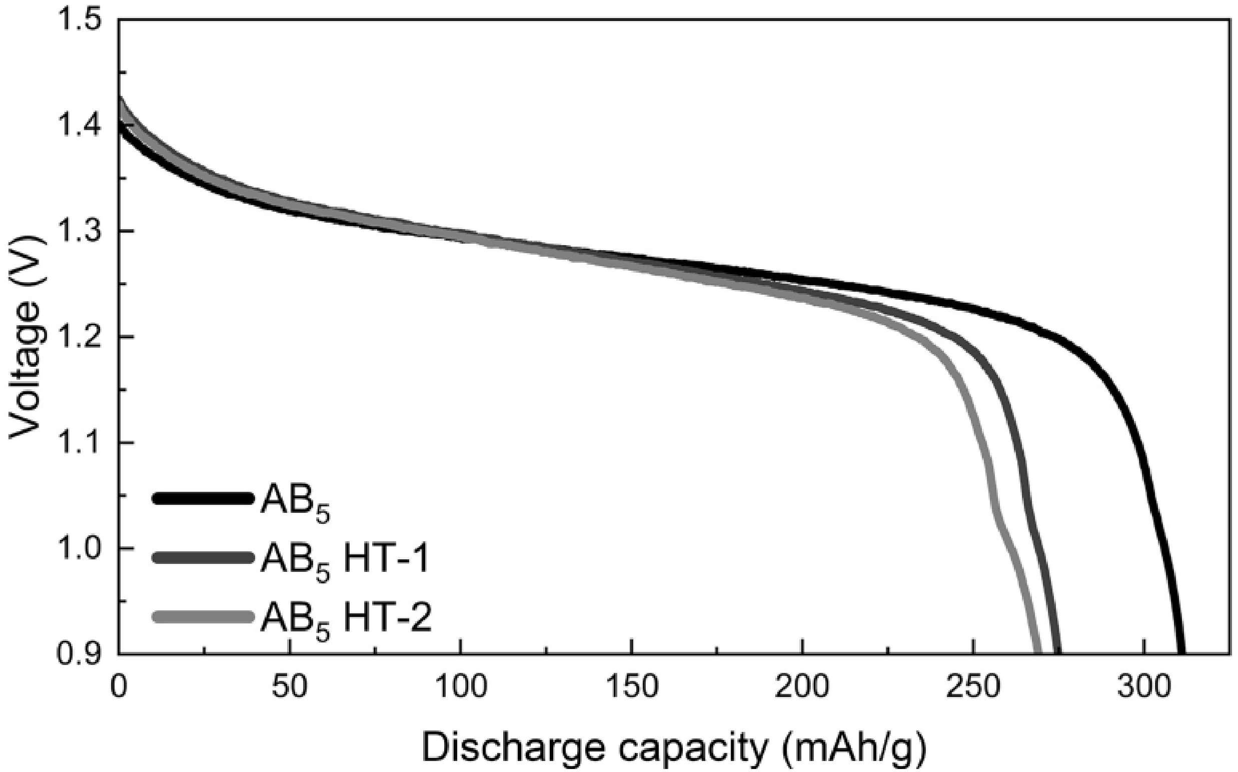


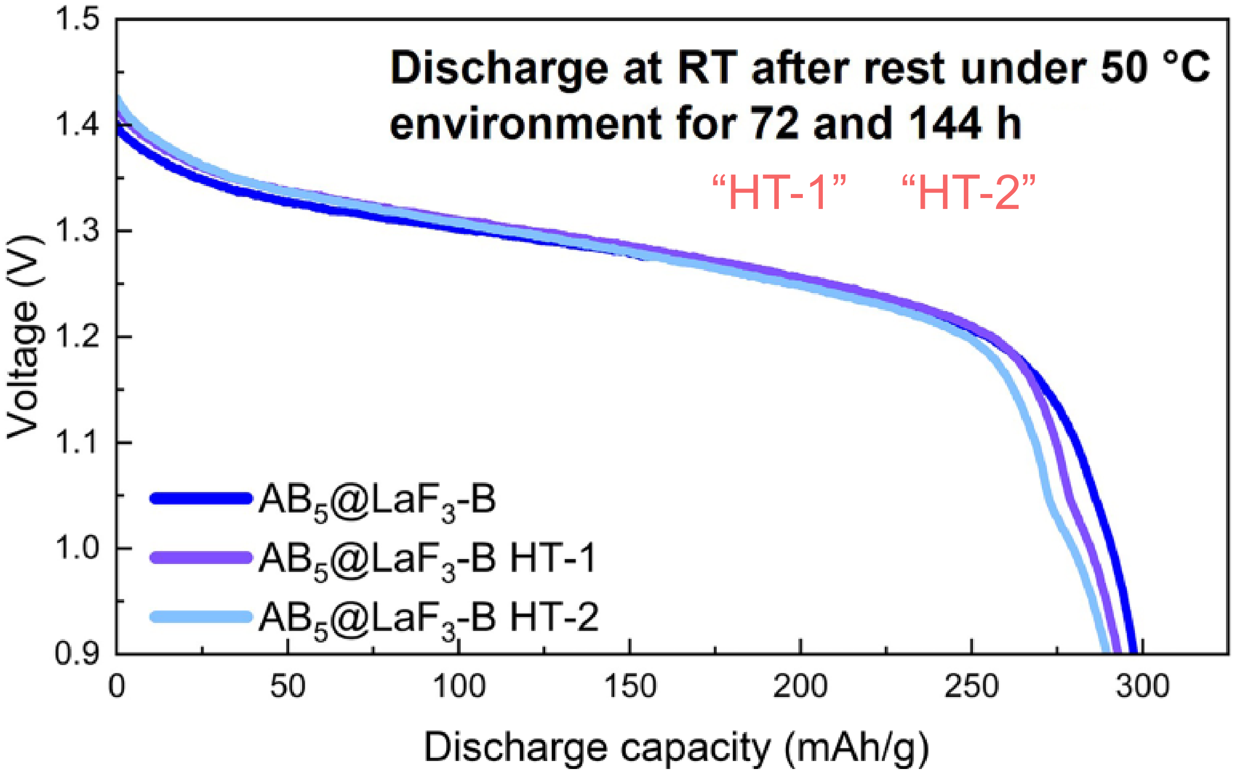
T can be even lower with anti-freezing electrolytes

Lower T limit for Li-ion: -20℃

Z. Chen, H. Liu, J. Nei, N. Liu*, ***Nano Research*** 2024, 17, 8819–8825

Stable cycling of NiMH battery anode via surface coating





Z. Chen, H. Liu, J. Nei, N. Liu*, ***Nano Research*** 2024, 17, 8819–8825

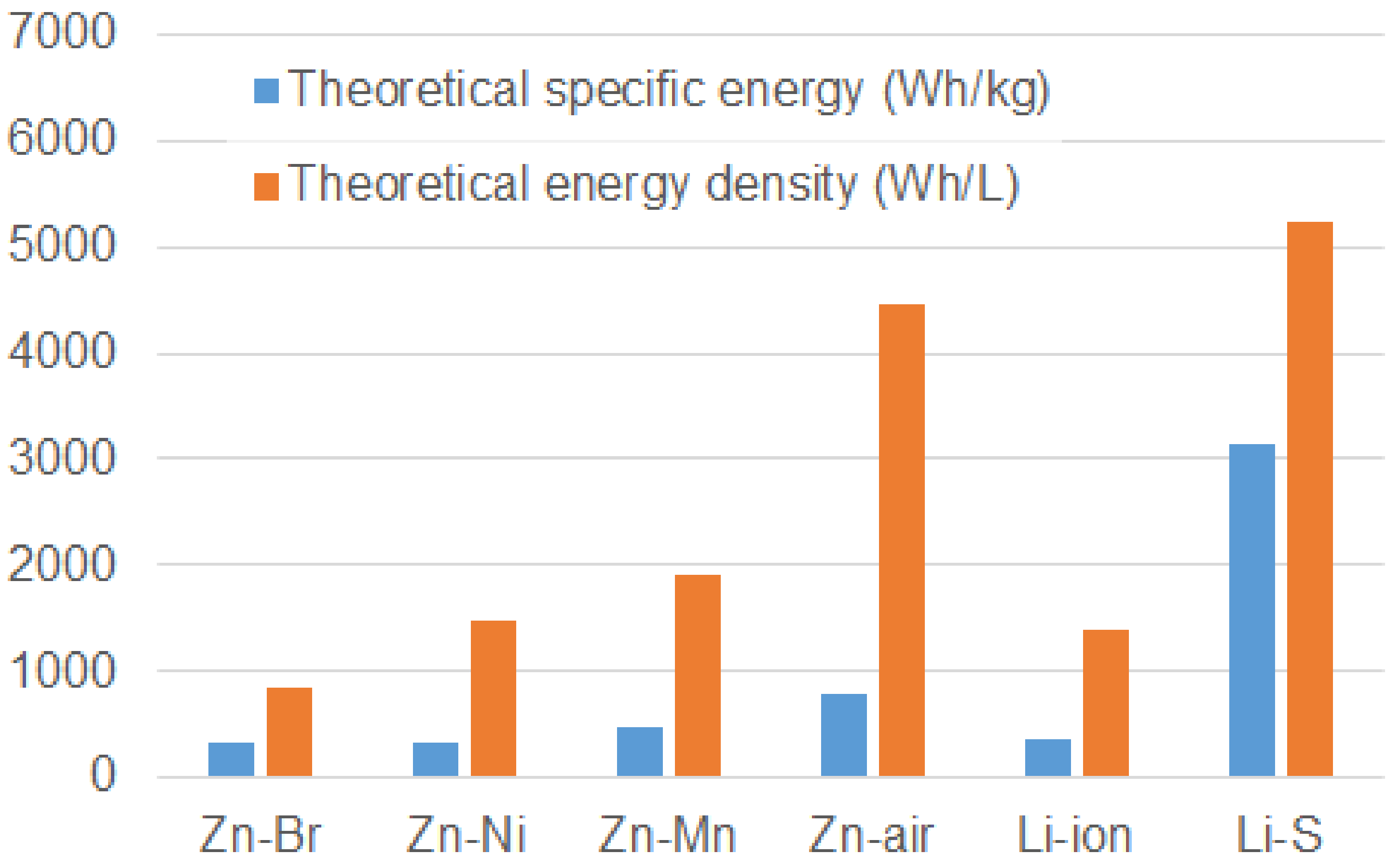
Part I

Enhancing the rechargeability of high-power nickel metal hydride anode

Part II

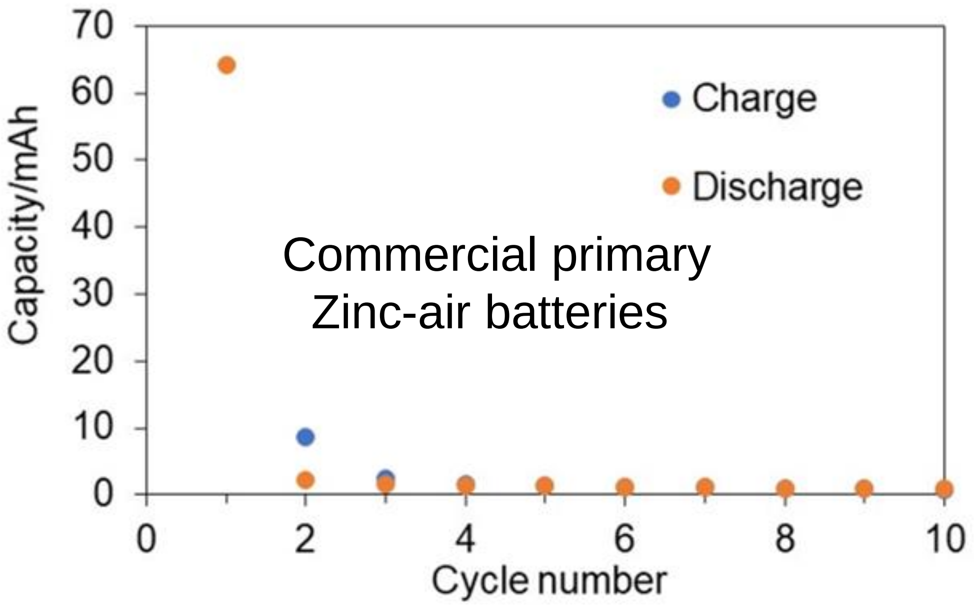
Enhancing the rechargeability and utilization of zinc anode

Intrinsic flammability of Li-ion & opportunity of Zn-based aqueous batteries

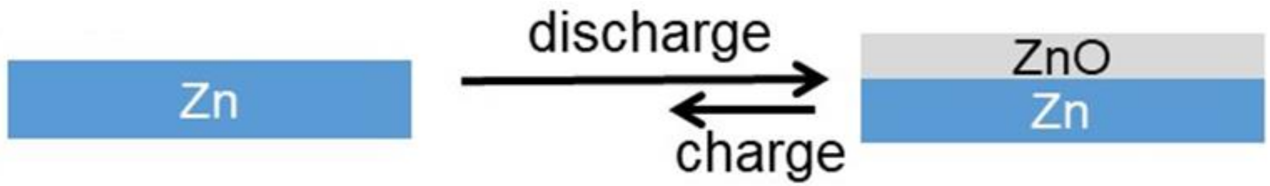


Irreversibility of Zn anode in alkaline electrolyte

Root cause #1:
ZnO passivation

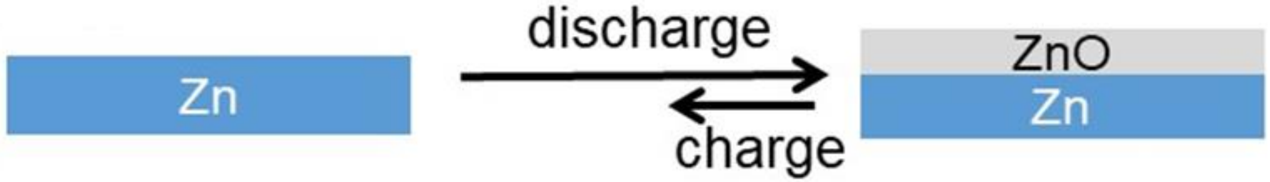


- Cannot deeply discharge (low utilization)
- Cannot recharge (poor reversibility)

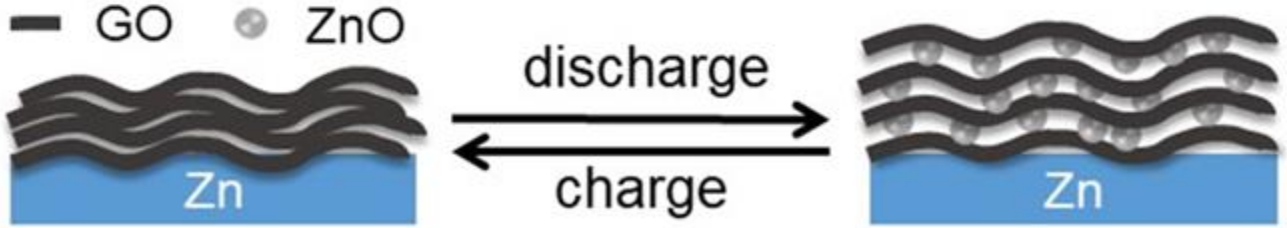


Z.-H. Wu, Y. Zhang, N. Liu*, ***Mater. Today Nano*** 6, 100032 (2019)

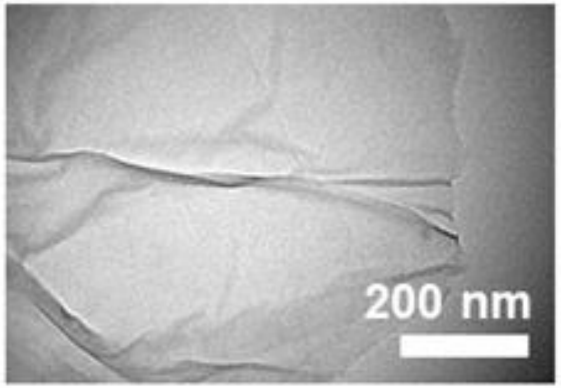
Introducing conductive host to recharge ZnO

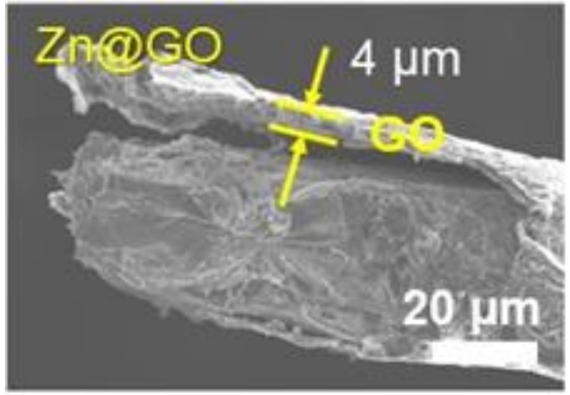


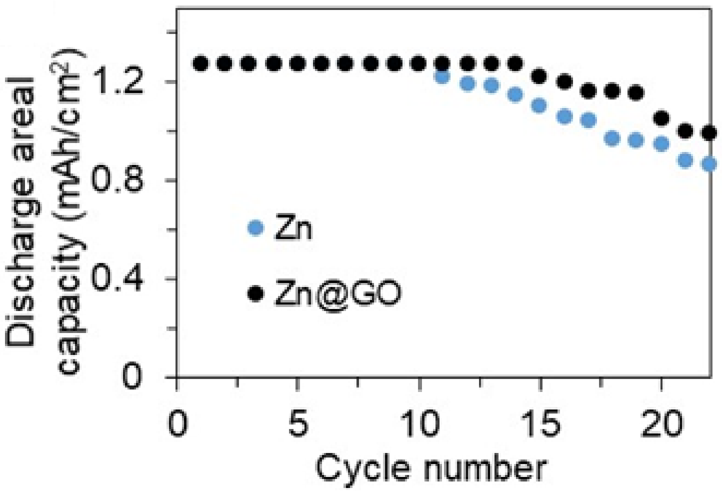
Zn

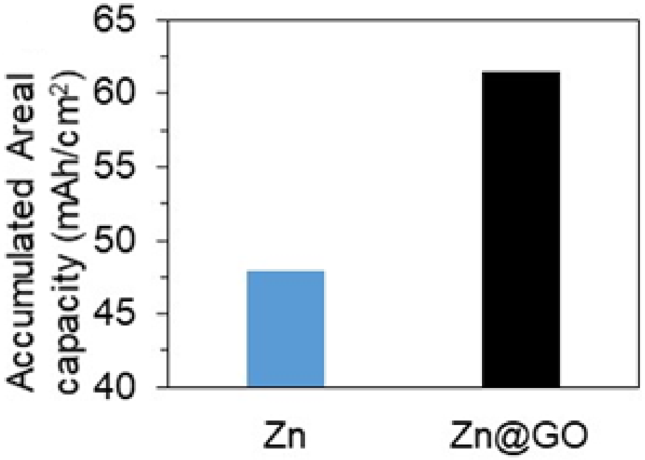


Zn@GO





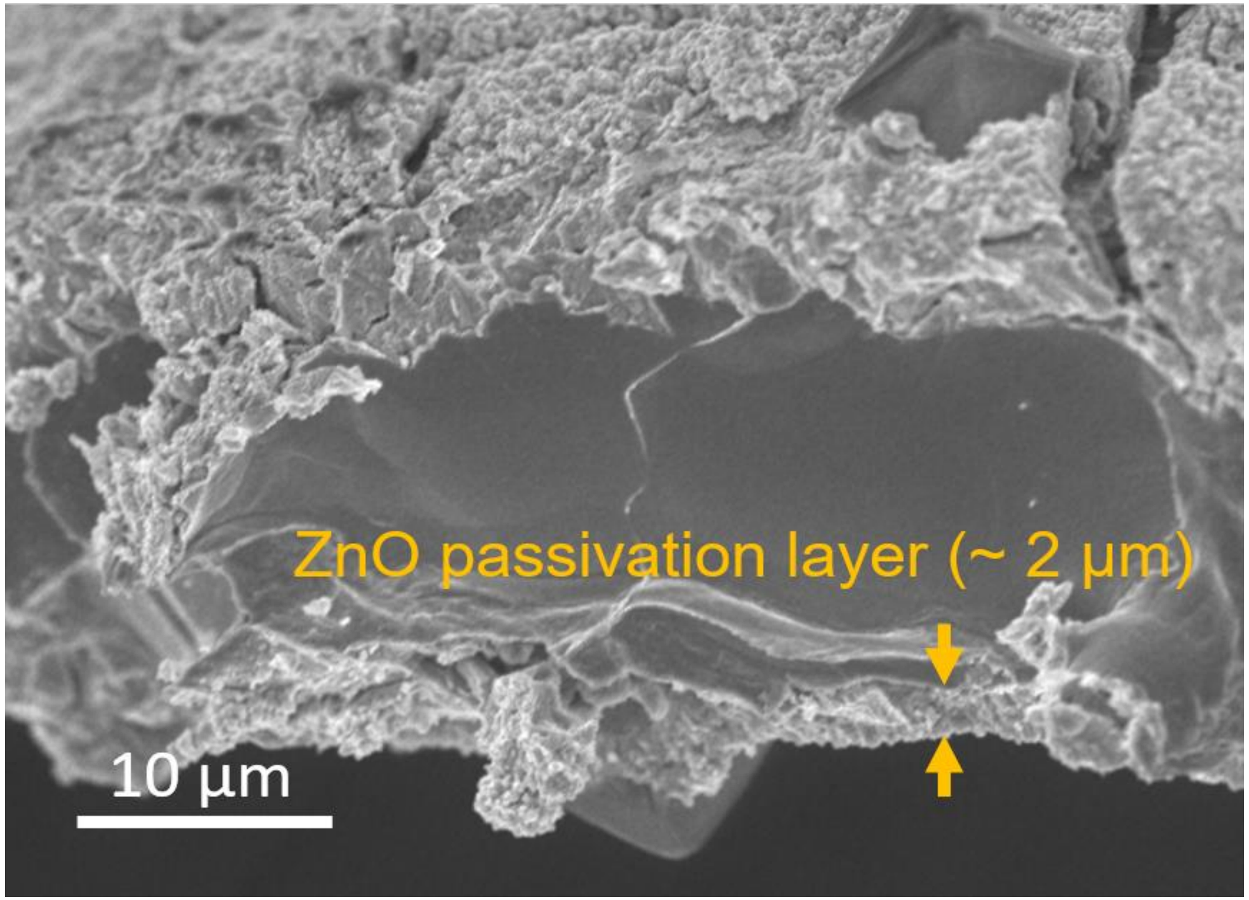




Z. Zhou, Y. Zhang, N. Liu*, et al. ***Chem. Eng. Sci.*** 194, 142-147 (2019)

Only utilize the surface → fully utilize the bulk

(Breaking the tradeoff between utilization and rechargeability)



ZnO critical passivation thickness:

~2um

Our hypothesis:

Decreasing the feature size

of Zn/ZnO to under 2um

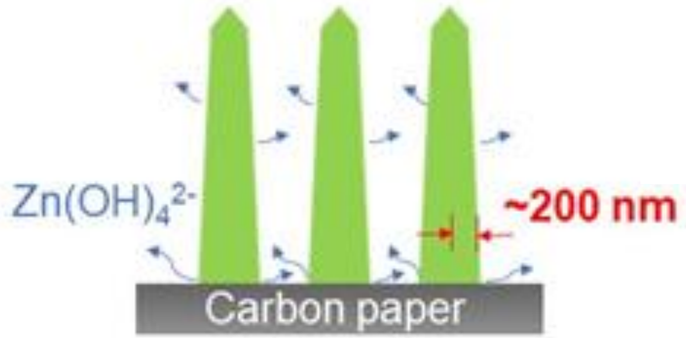
can avoid passivation

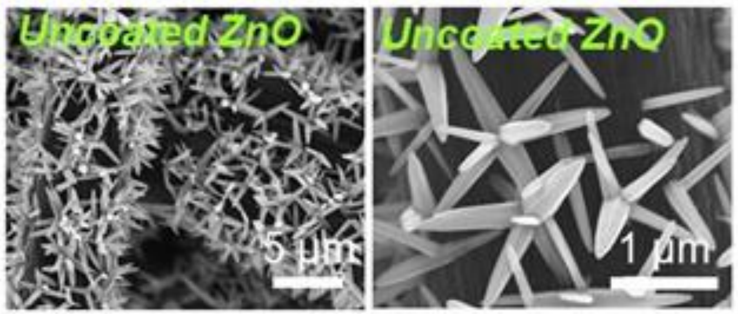
Y. Zhang, N. Liu*, et al. ***Nano Energy*** 53, 666-674 (2018)

Irreversibility of Zn anode in alkaline electrolyte

Root cause #1: ZnO passivation

Root cause #2: Zincate dissolution



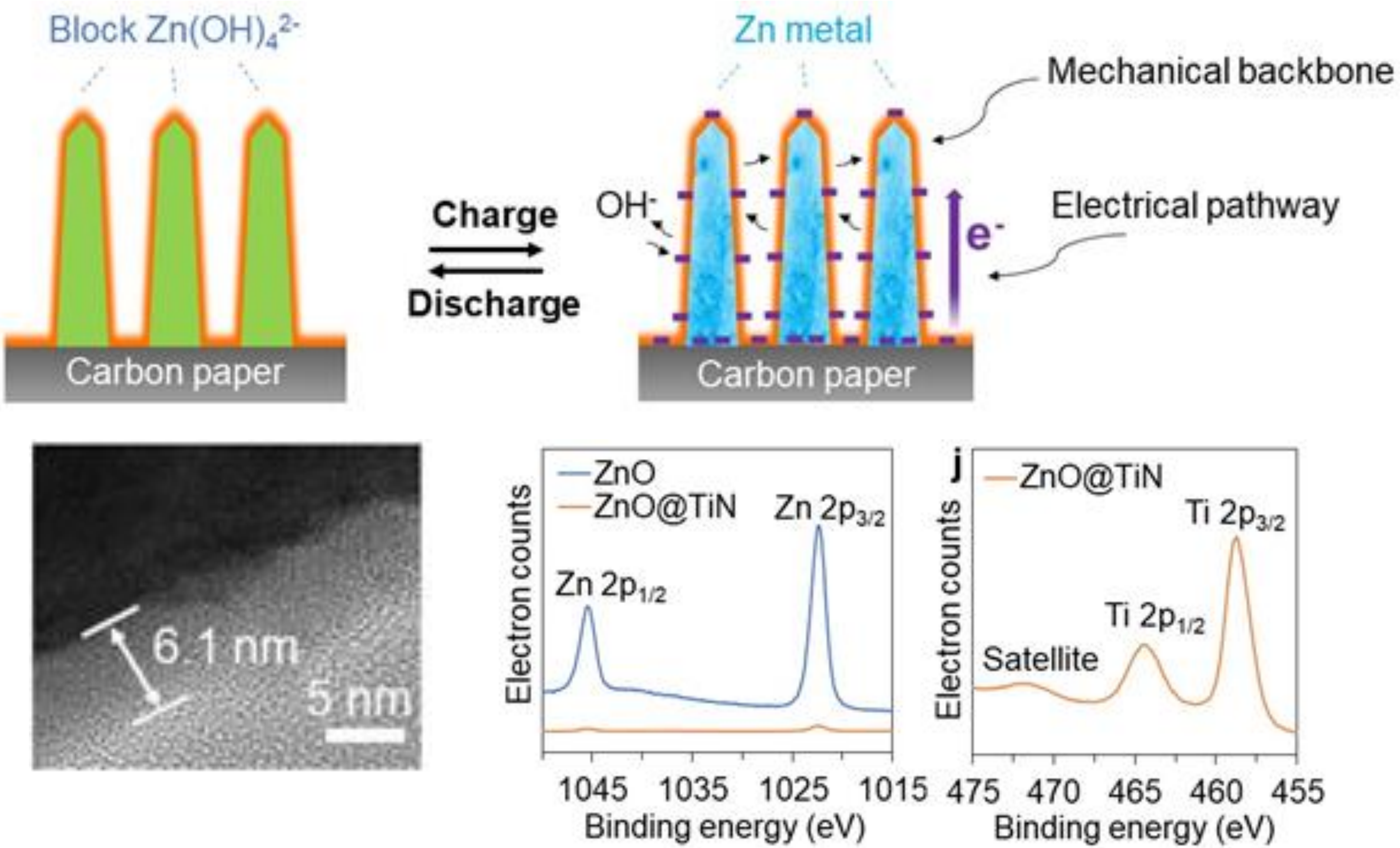


$$ZnO + H_2O + 2OH^- \leftrightarrow Zn(OH)_4^{2-}$$

$$Zn(OH)_4^{2-} + 2e^- \leftrightarrow Zn + 4OH^-$$

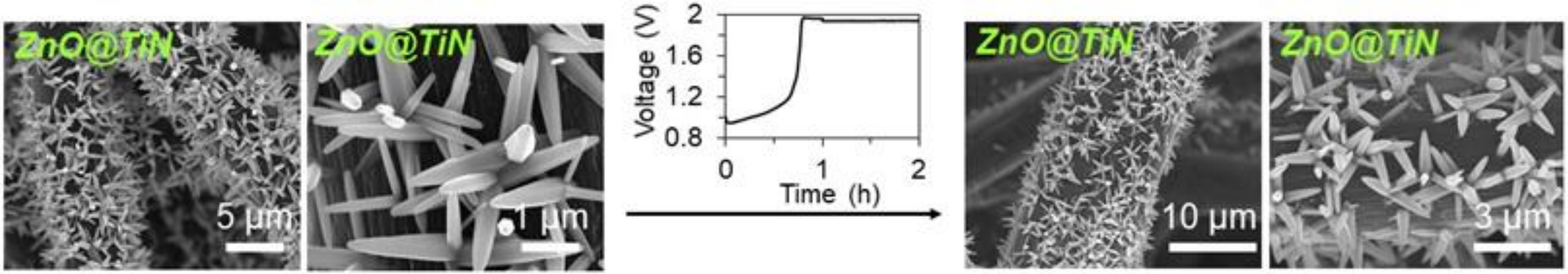
Y. Zhang, N. Liu*, et al. ***Nano Energy*** 53, 666-674 (2018)

Sealed ZnO nanorod anode

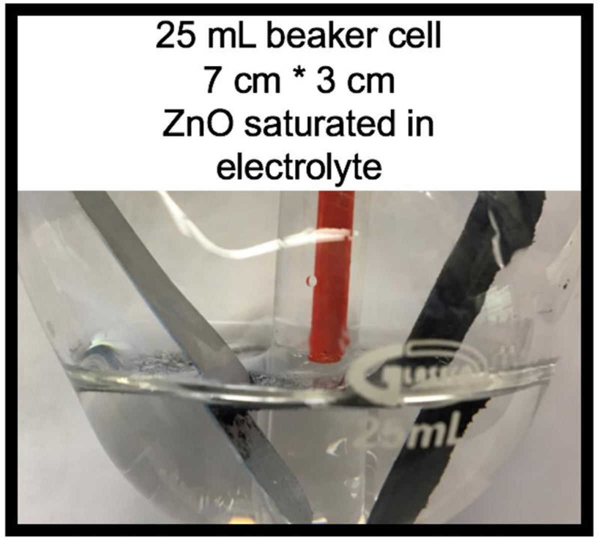


Y. Zhang, N. Liu*, et al. ***Nano Energy*** 53, 666-674 (2018)

Sealed ZnO nanorod anode

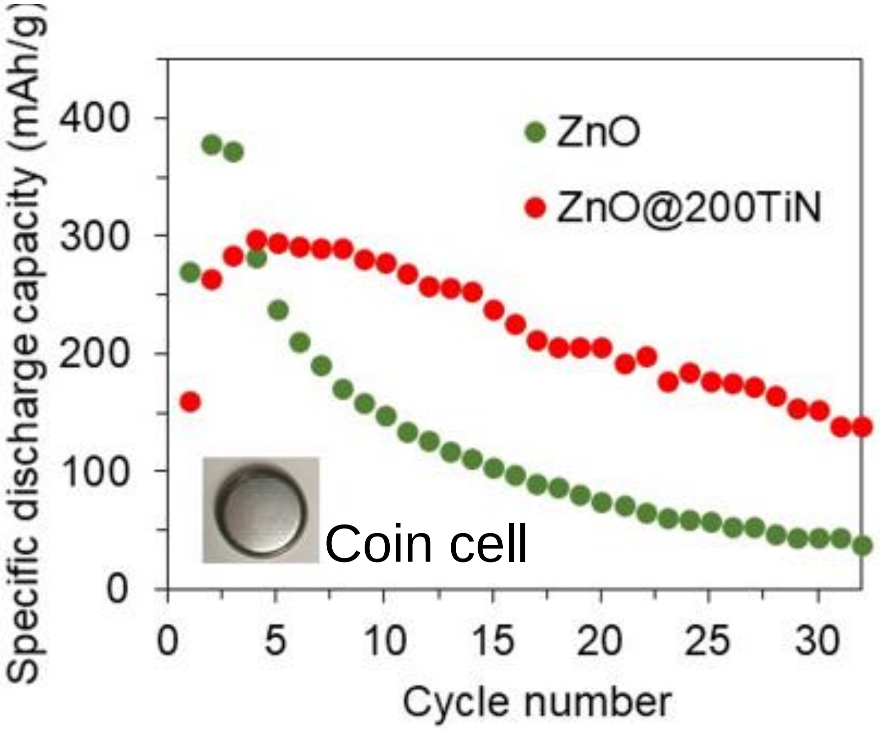


Y. Zhang, N. Liu*, et al. ***Nano Energy*** 53, 666-674 (2018)



Most previous articles

rsh testing condition:
linimum electrolyte
o ZnO saturation
00% depth-of-discharge



Y. Zhang, N. Liu*, et al. ***Nano Energy*** 53, 666-674 (2018)

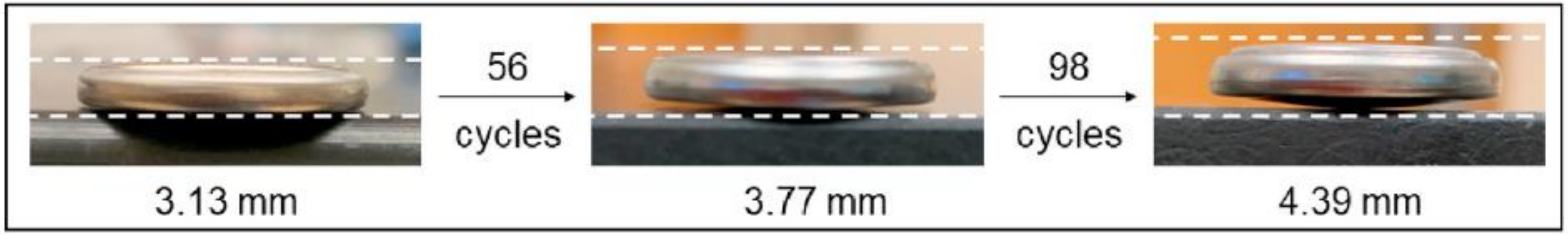
Irreversibility of Zn anode in alkaline electrolyte

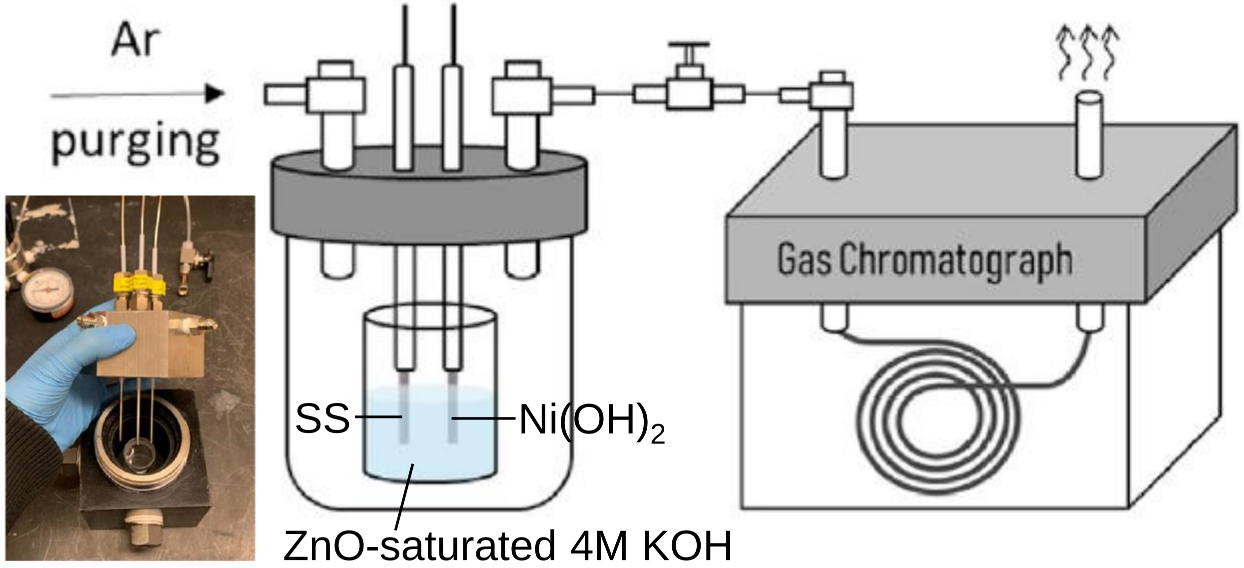
Root cause #1: ZnO passivation

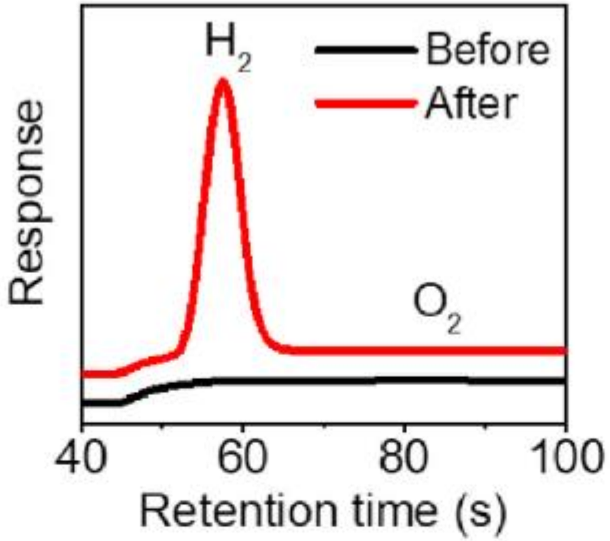
Root cause #2: Zincate dissolution

Root cause #3: Hydrogen evolution

Stainless-steel coin cell thickness measurement over cycling

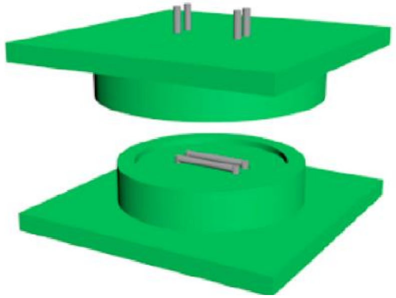






~~Stainless steel coin cell~~

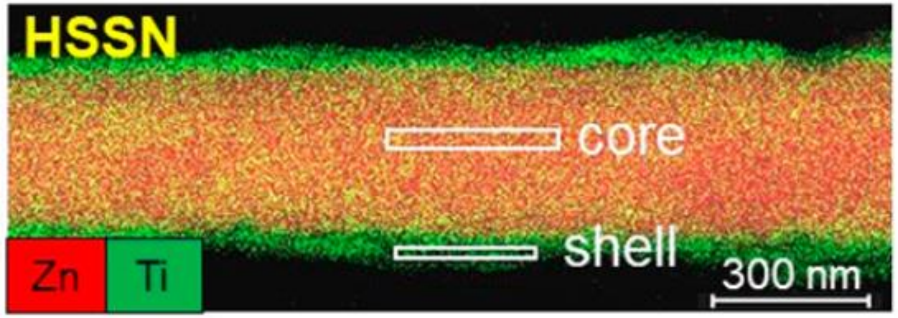
Pouch cell

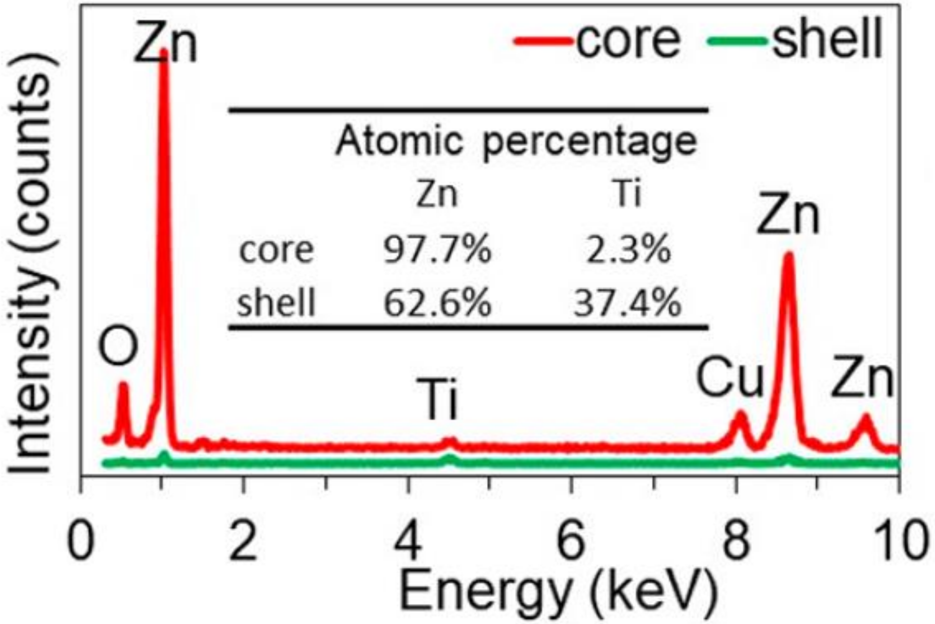


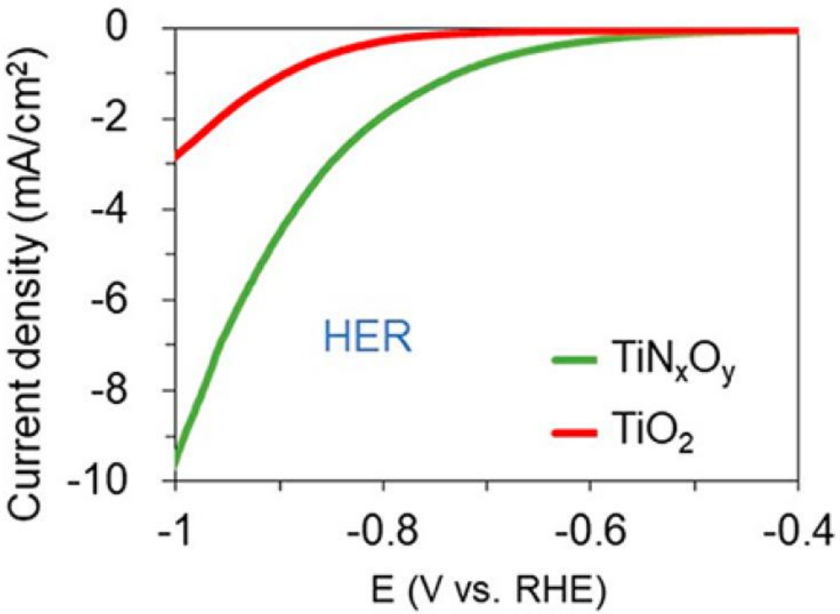
PTFE cell

Y. Zhang, A. Mathur, N. Liu* et al. ***J. Power Sources*** 491, 229547 (2021)

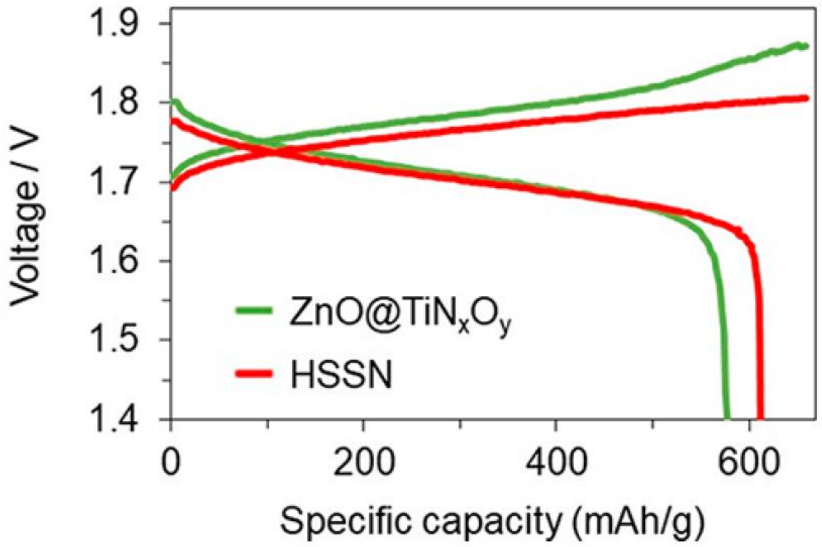
HER-suppressing sealed nanosized (HSSN) zinc anode







TiO_2 coating has low HER activity

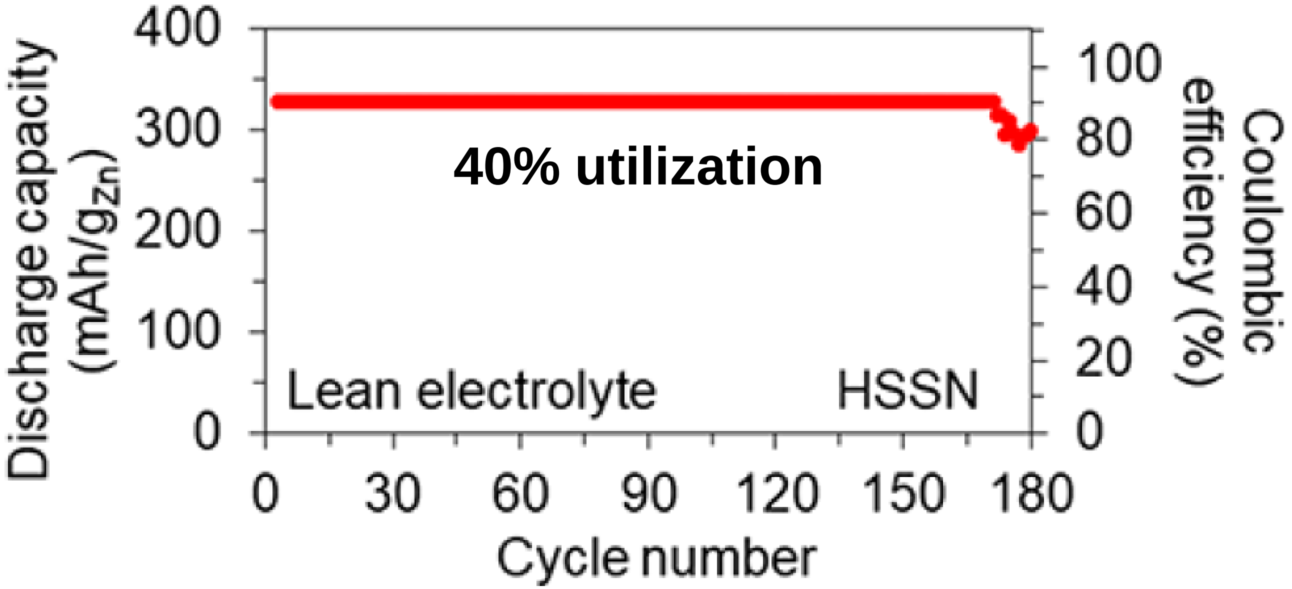


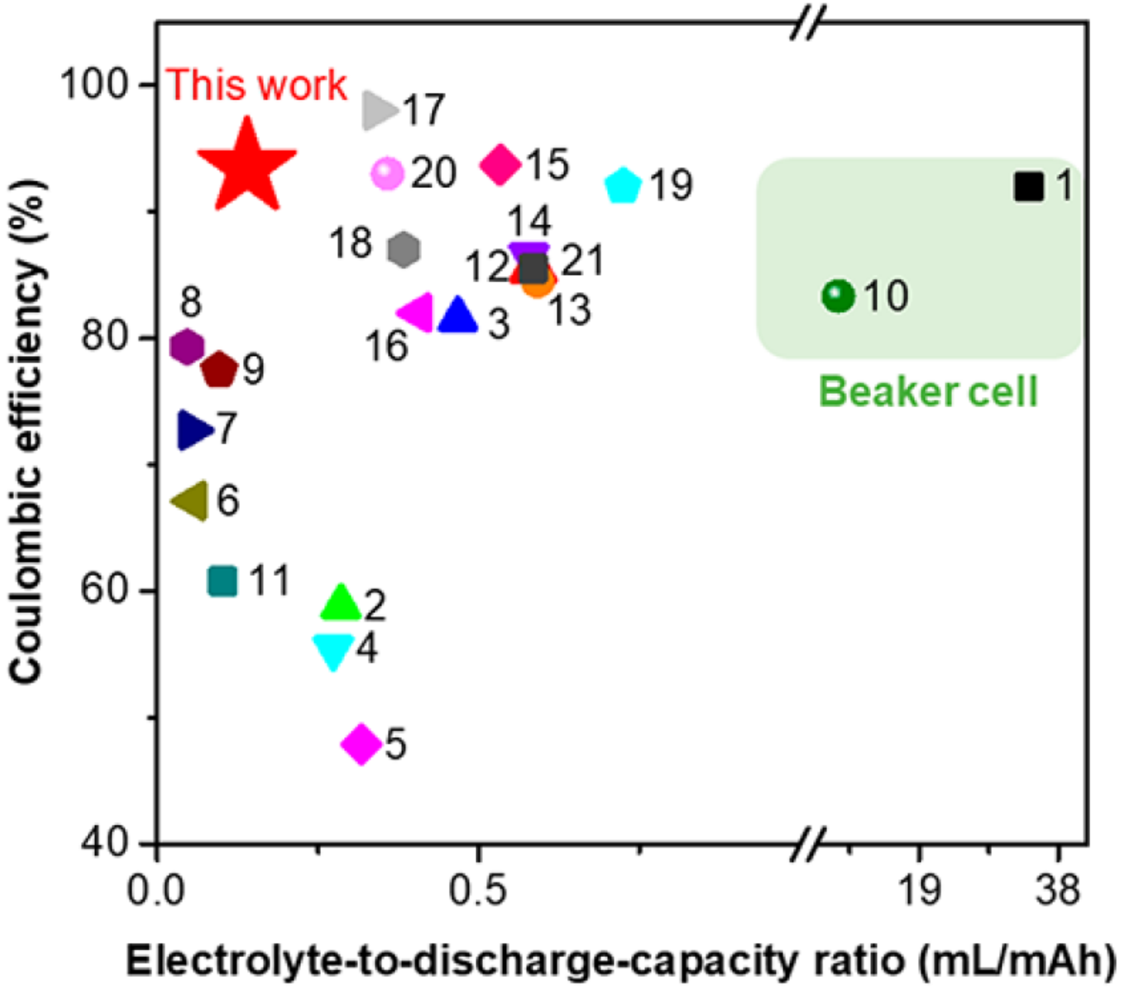
Improved Coulombic efficiency

85.0% → 93.5%

Y. Zhang, N. Liu* et al. ***Nano Lett.*** 20 (6), 4700–4707 (2020)

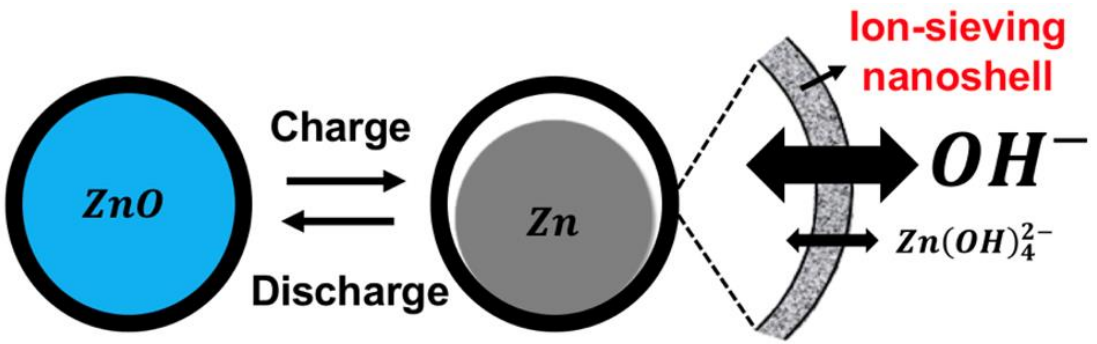
HER-suppressing sealed nanosized (HSSN) zinc anode

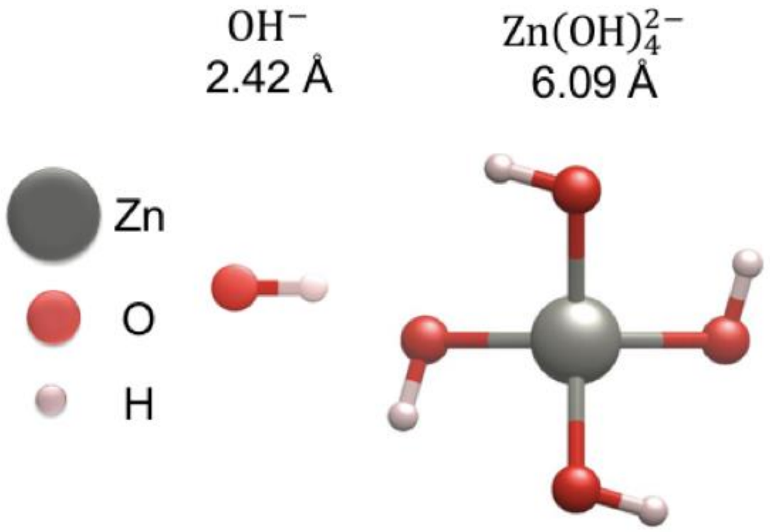


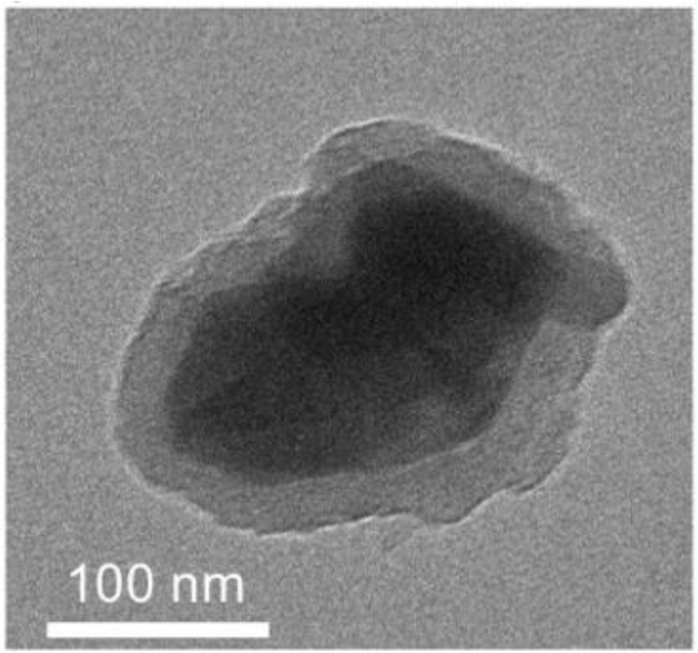


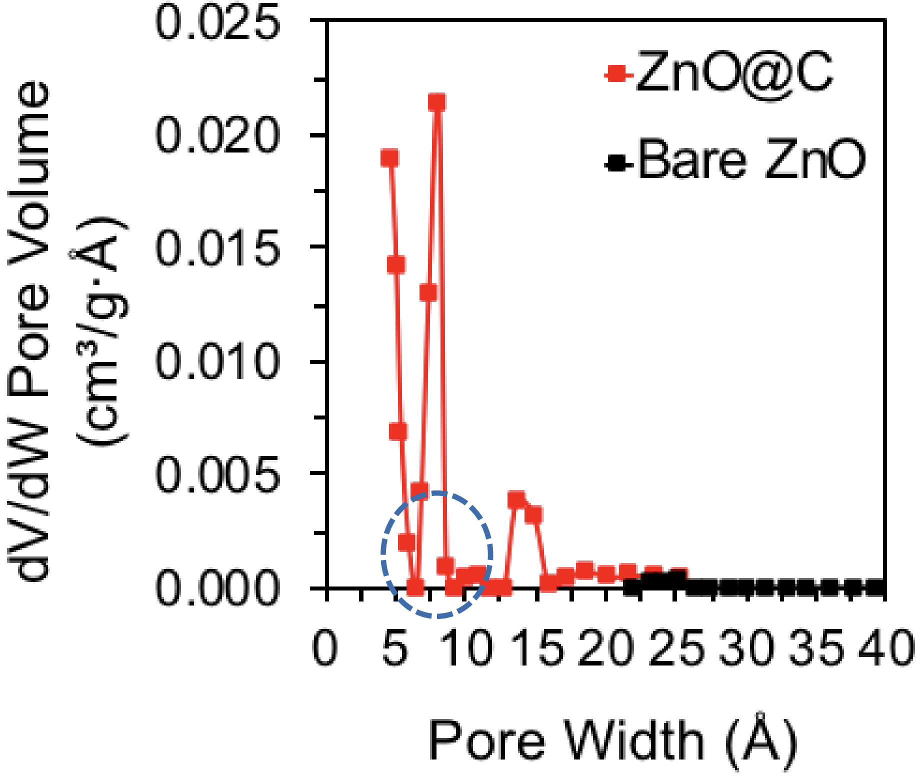
Y. Zhang, N. Liu* et al. ***Nano Lett.*** 20 (6), 4700–4707 (2020)

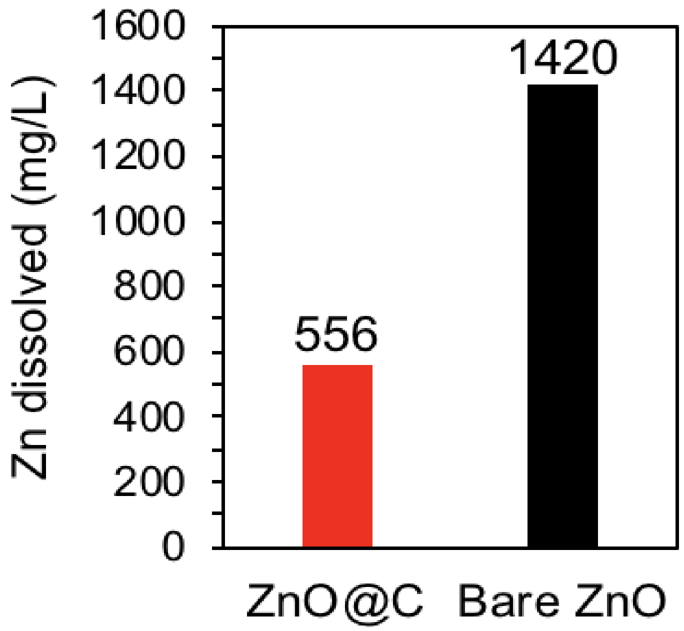
Particle-based anode material: ZnO @ ion-sieving carbon





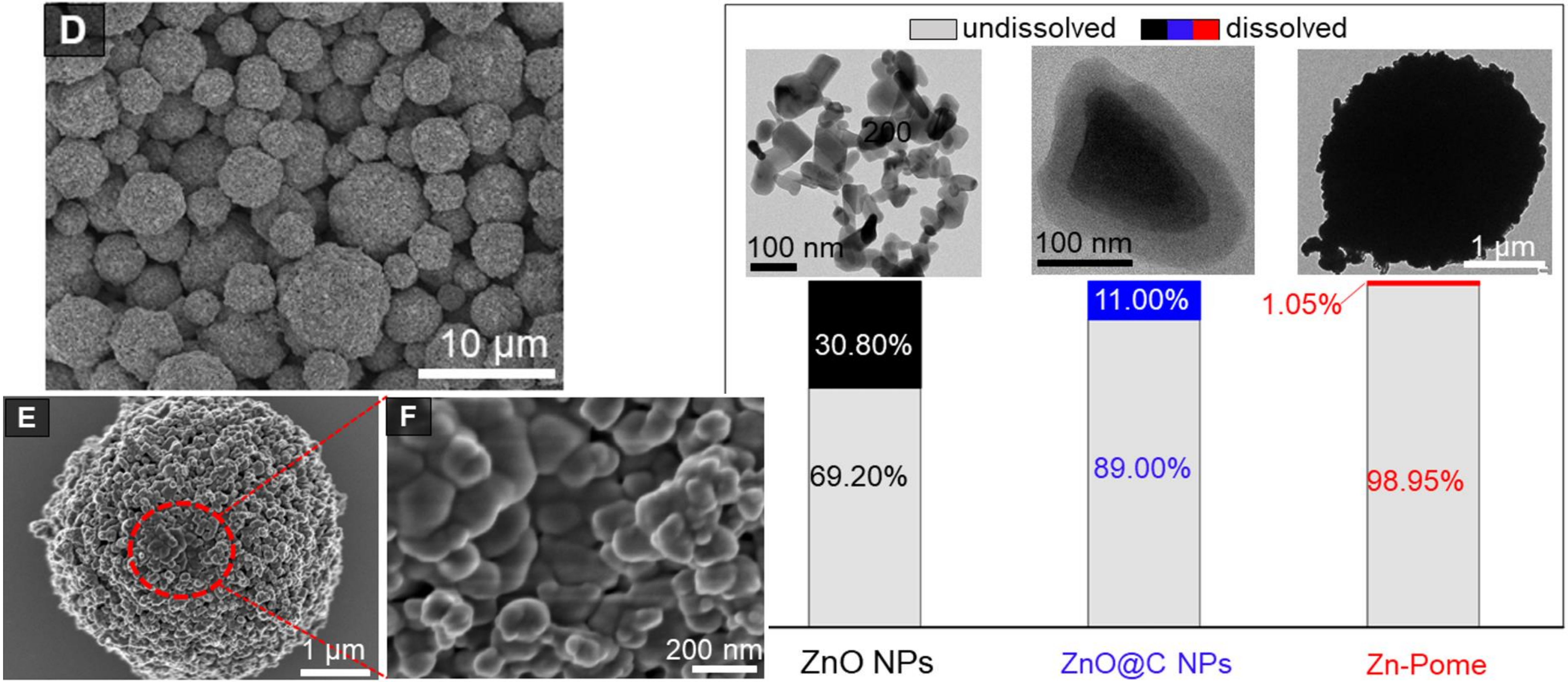






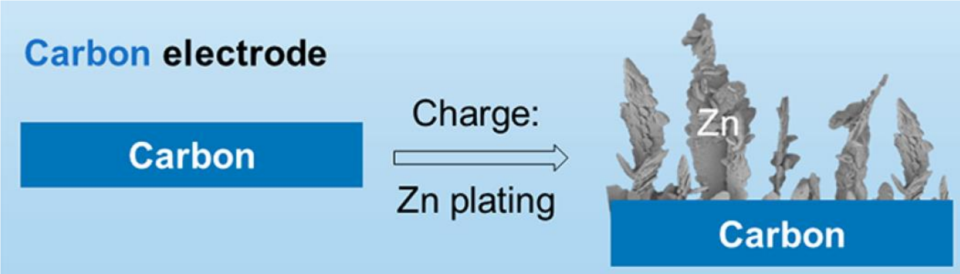
Y. Wu, N. Liu*, et al. ***Adv. Energy Mater.*** 8 (36), 1802470 (2018)

Further suppression of $Zn(OH)_4^{2-}$ dissolution: Pomegranate-structured ZnO/C anode (Zn-Pome)

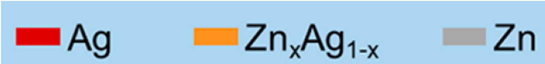


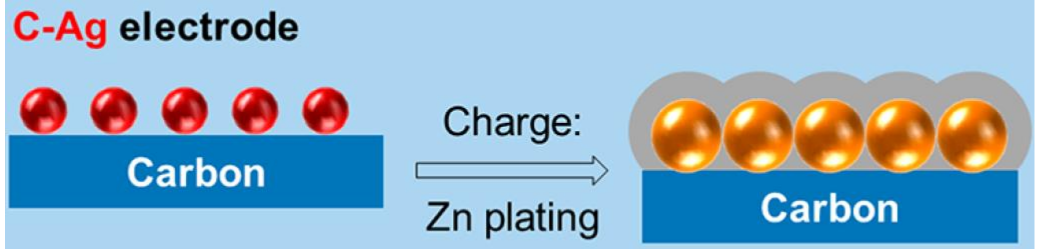
P. Chen, Y. Wu, N. Liu*, et al. ***J. Mater. Chem. A*** 6 (44), 21933-21940 (2018)

Soluble zincate: Passive encapsulation → Active management



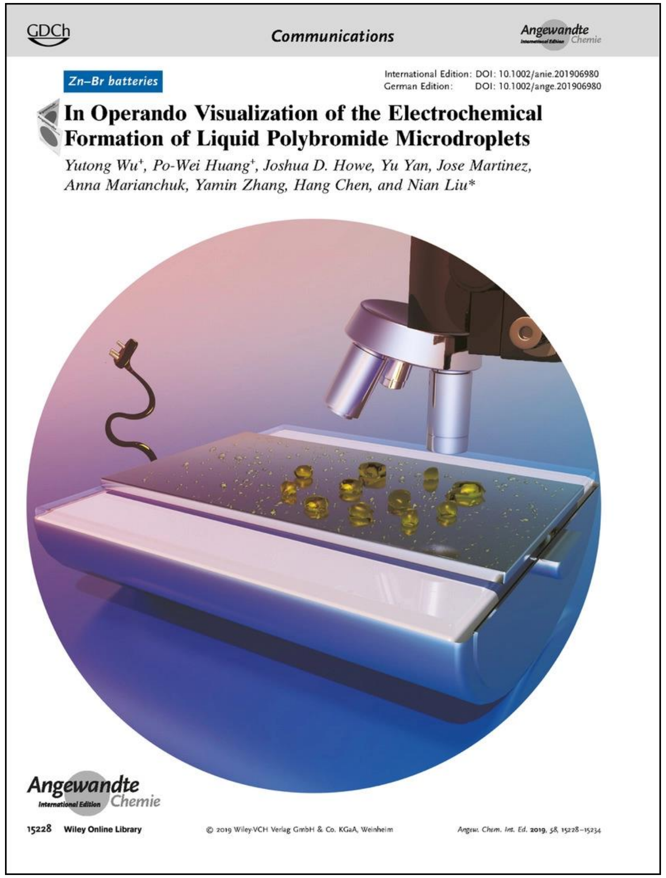
Y. Zhang, N. Liu* et al.
ACS Energy Lett.
2021, 6 (2), 404–412





Carbon fiber paper:

- Dendritic Zn deposition
- Dead Zn left behind results in capacity decay



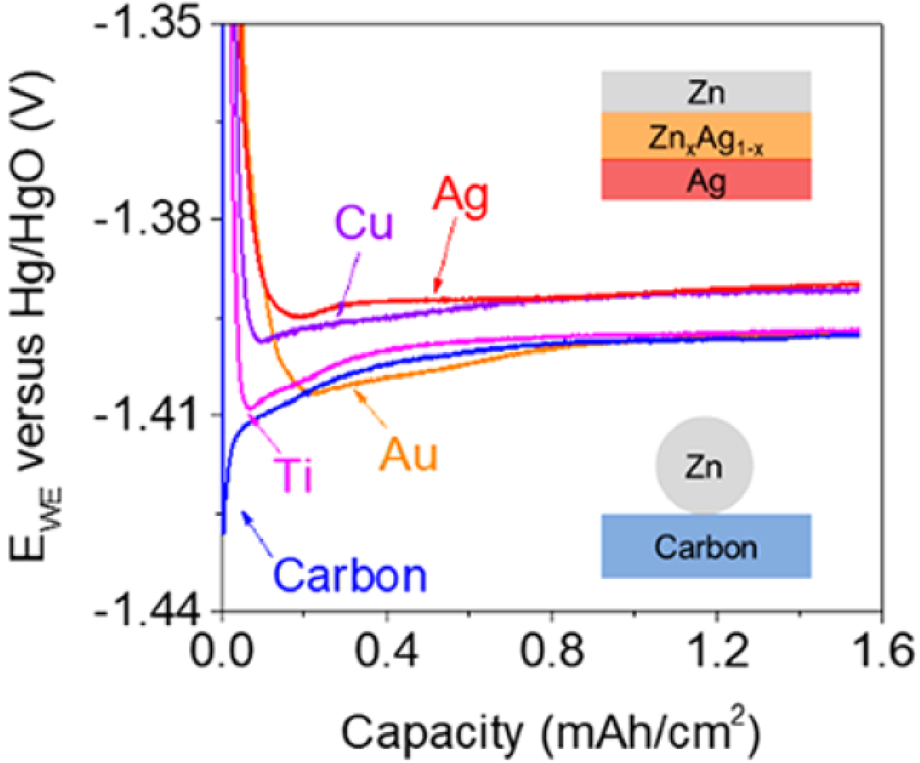
In operando
Optical Microscopy
for Visualizing
Battery Local Dynamics

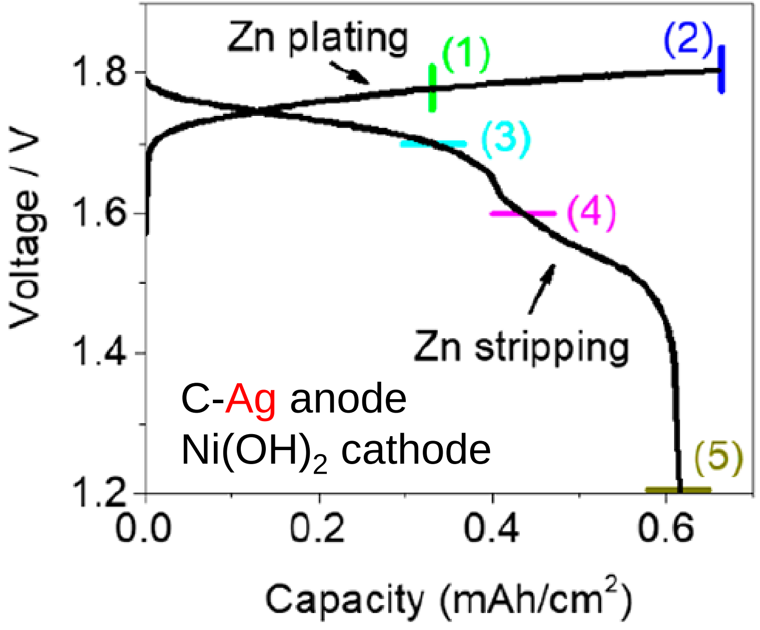
Angew. Chem. Int. Ed.
131 (43), 15372-15378 (2019)

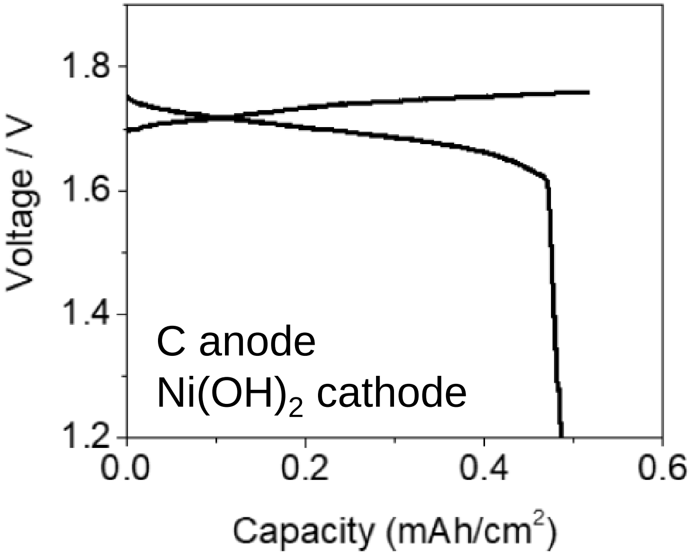
Proc. Natl. Acad. Sci. U.S.A
116 (3), 765-770 (2019)

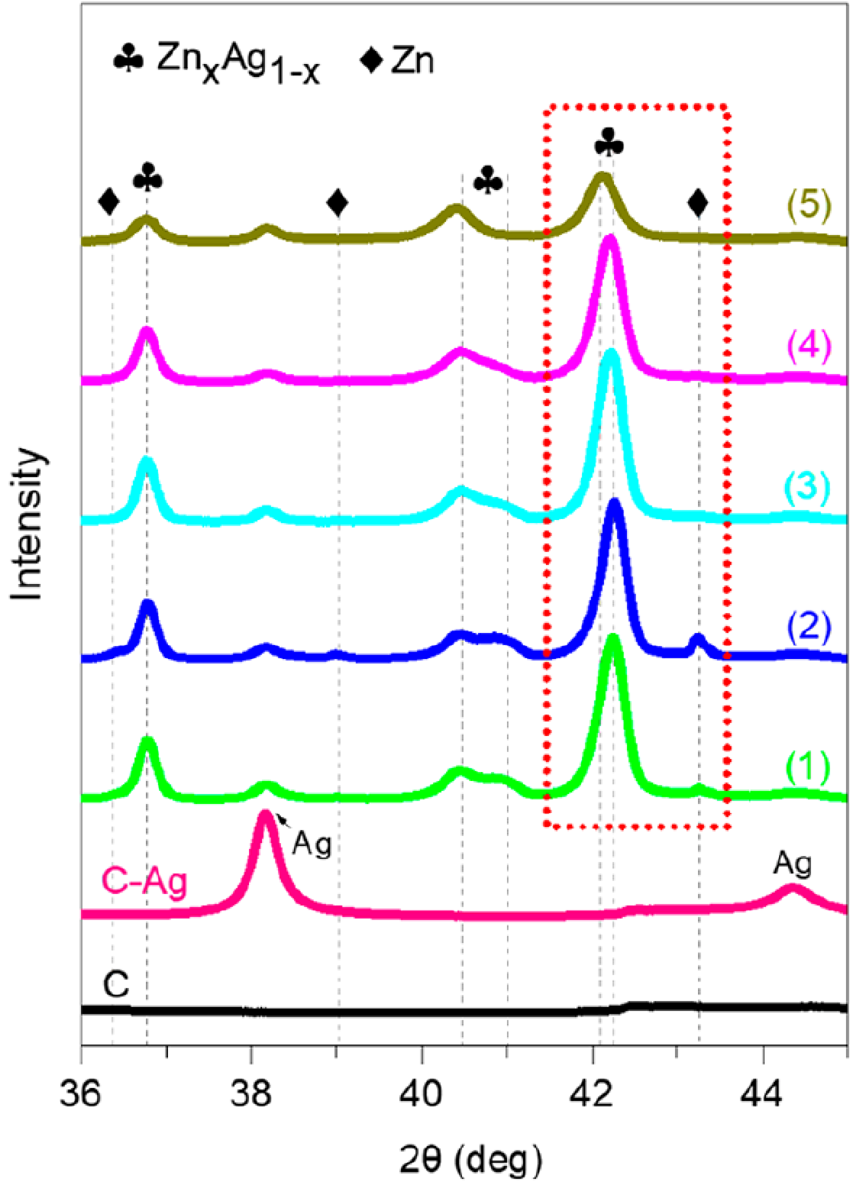
Nature Communications
11, 606 (2020)

Alloy-seeded Zn anode: mechanism





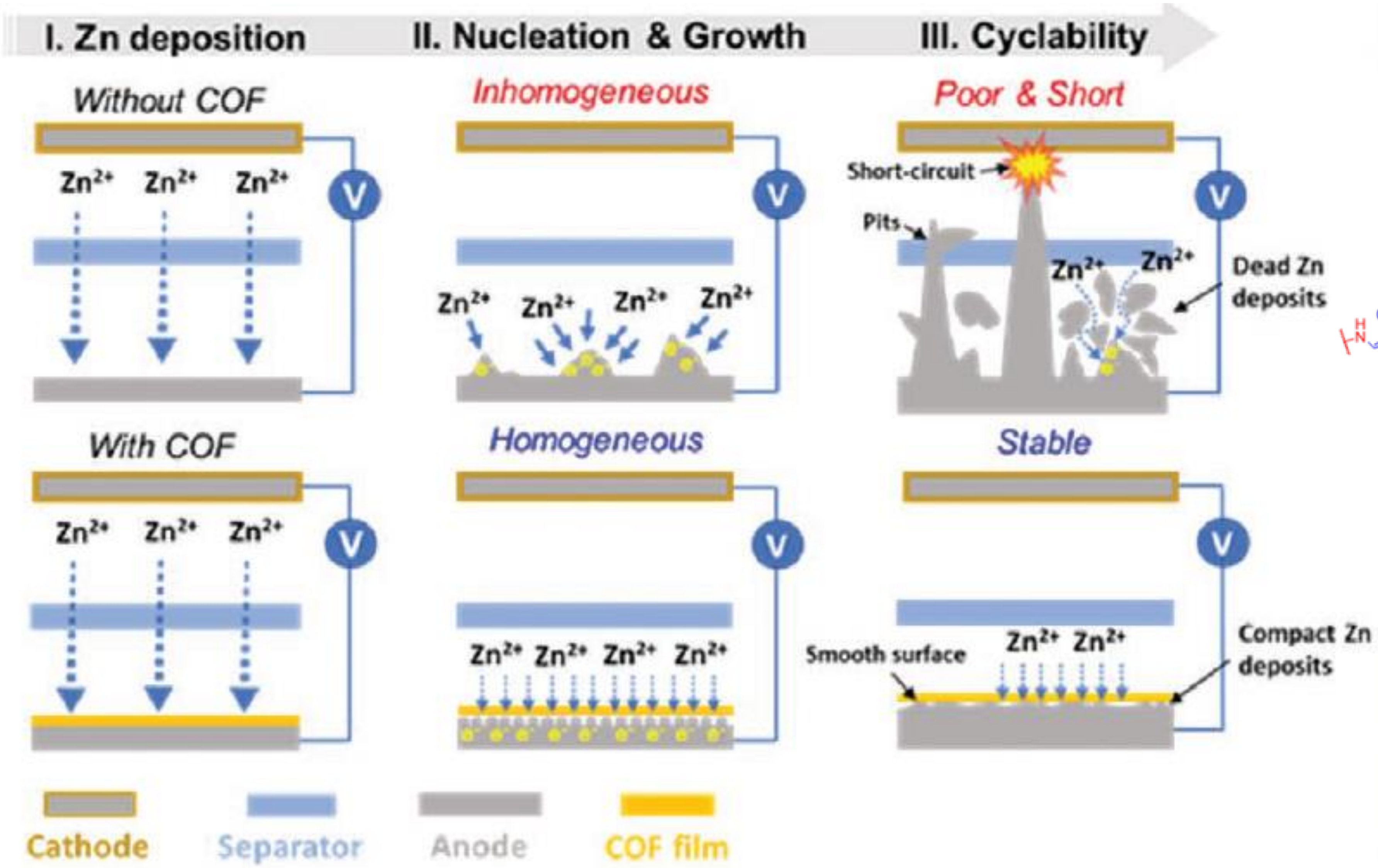


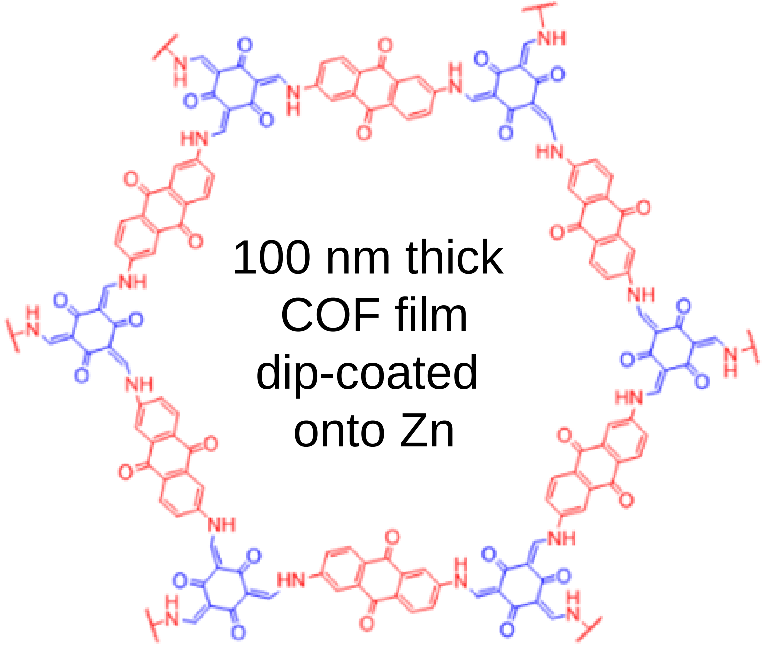


Y. Zhang, N. Liu* et al. ***ACS Energy Lett.*** 2021, 6 (2), 404–412

Covalent organic framework (COF) coating

Another approach to control morphology of Zn electrodeposits





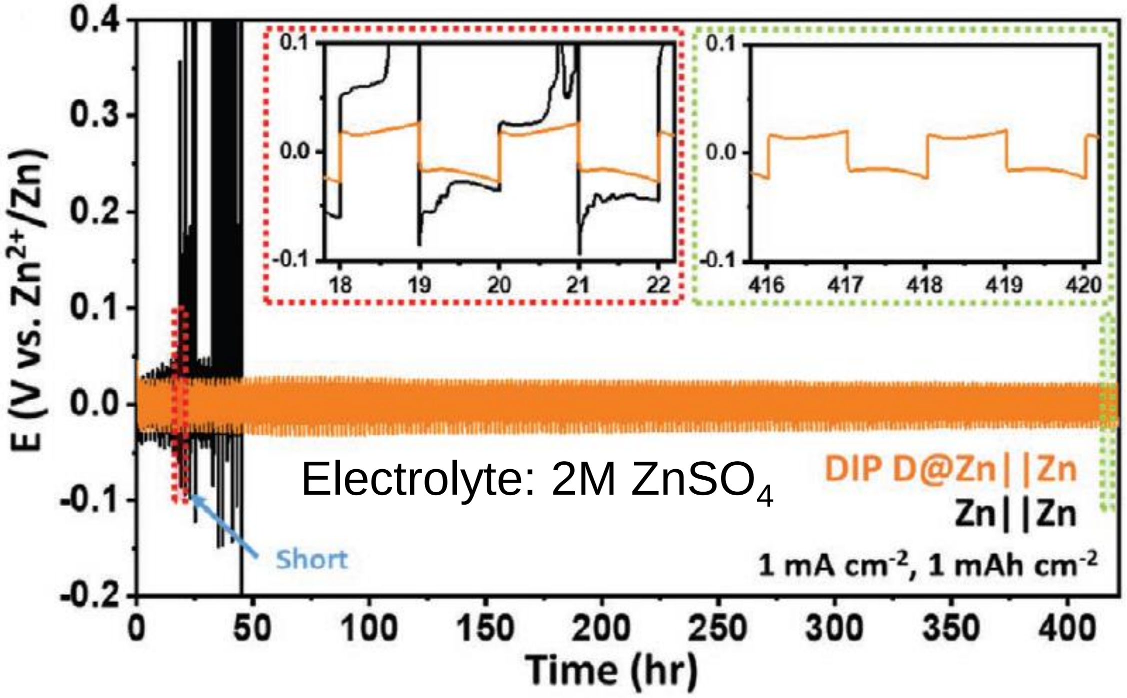
Screened nine COFs with 1-10 nm pore aperture.

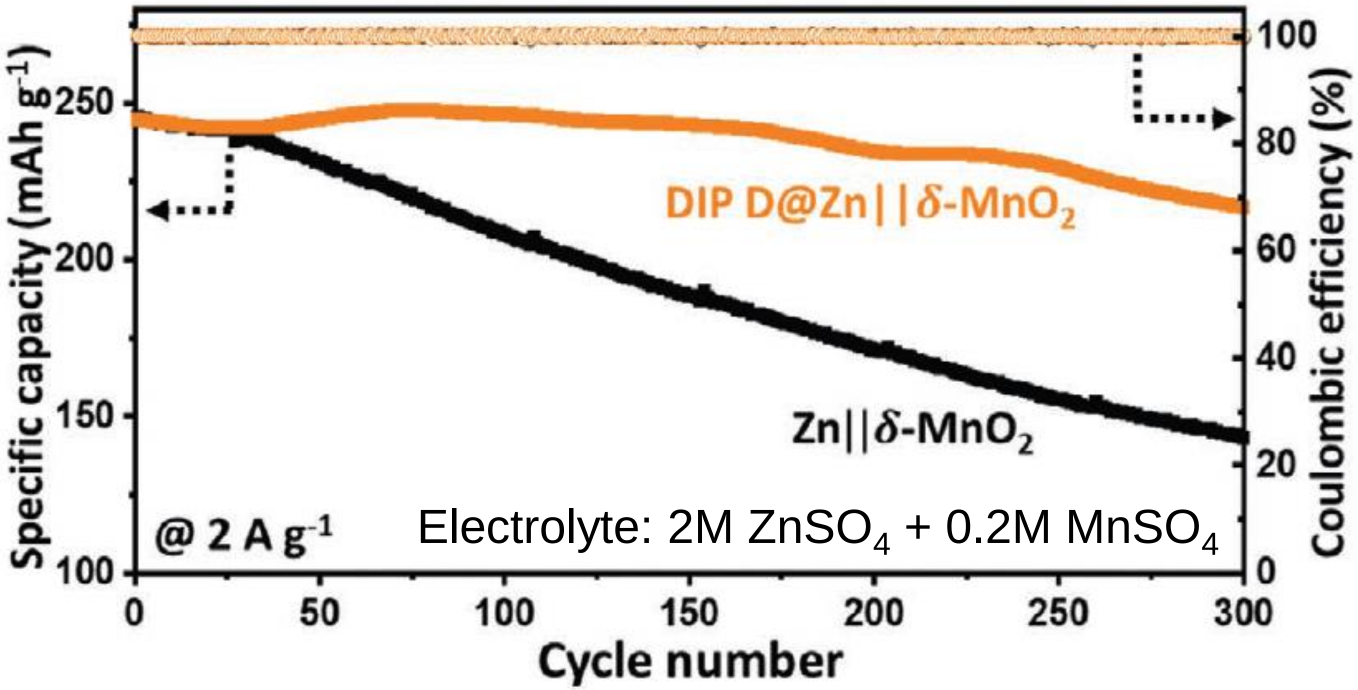
The best performing one has:

1. Hydrophobic pores
2. Affinity to Zn^{2+}

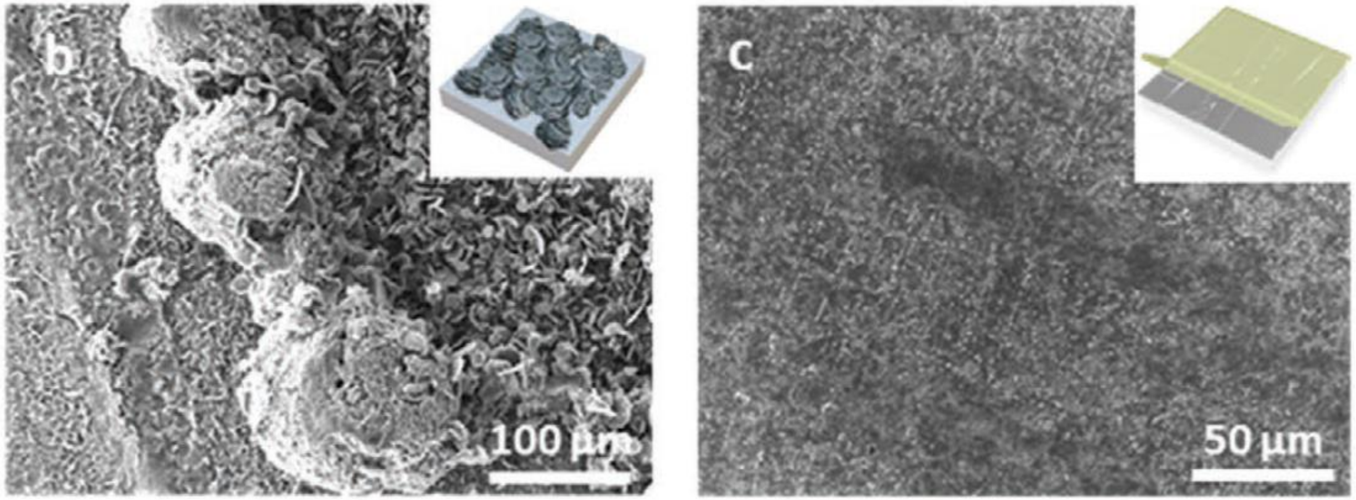
Park, Kwak, Hwang, Kang, Liu, Jang, Grzybowski, ***Adv. Mater.*** 33 (34), 2101726 (2021)

Covalent organic framework (COF) coated Zn foil anode



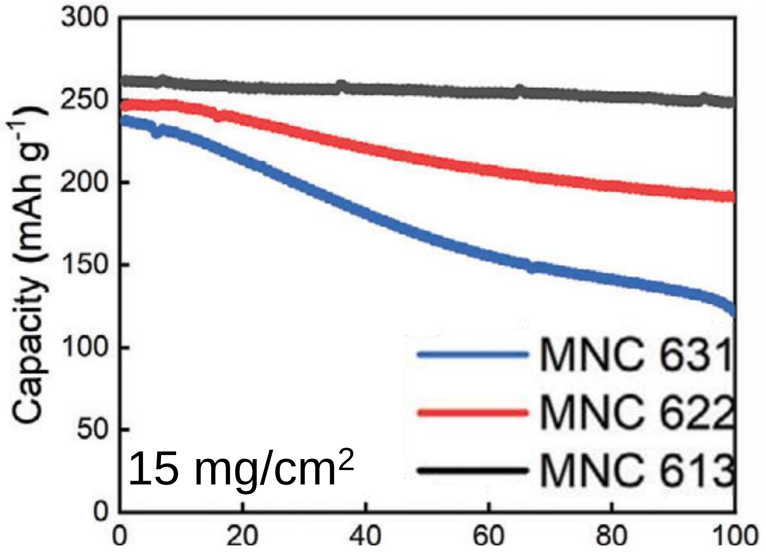


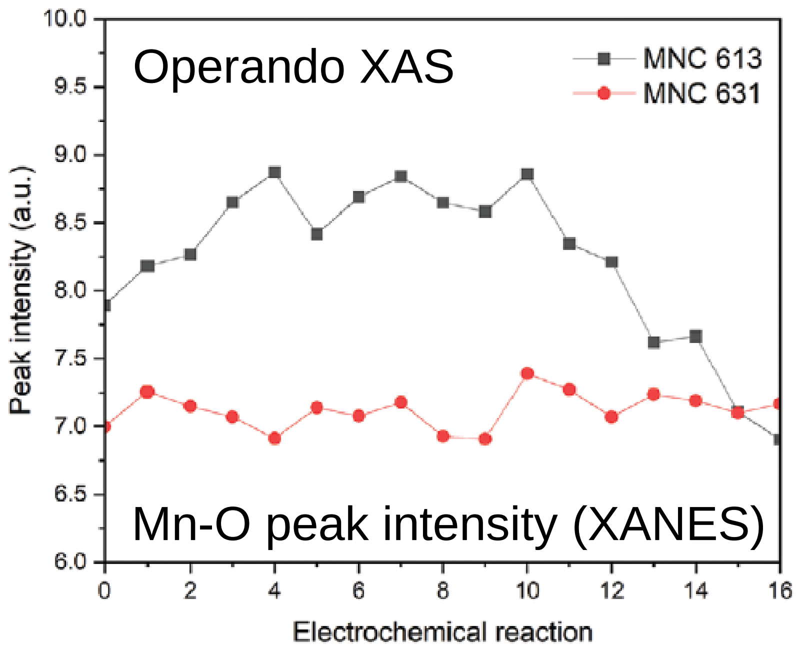
After 20 cycles:

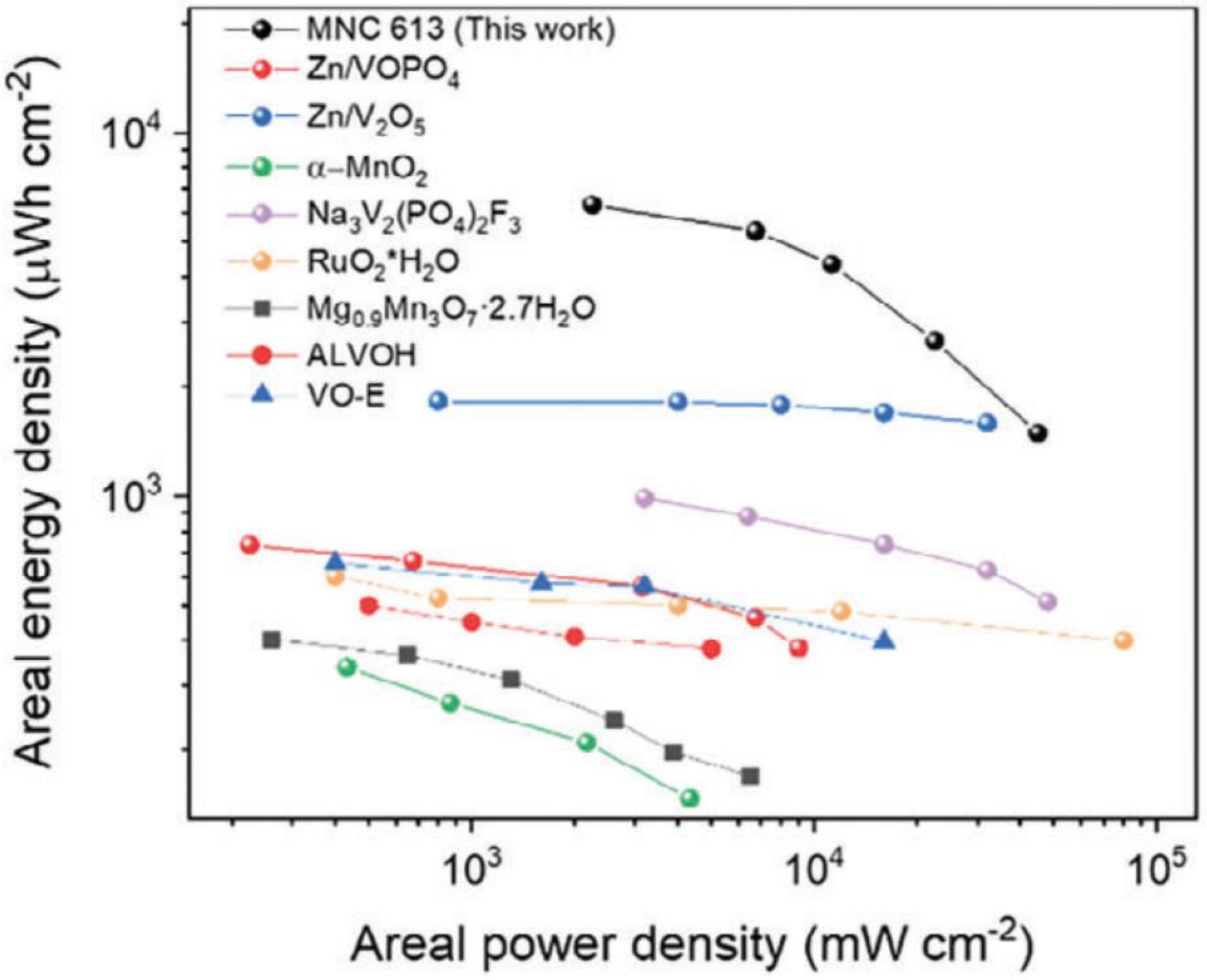


Park, Kwak, Hwang, Kang, Liu, Jang, Grzybowski, ***Adv. Mater.*** 33 (34), 2101726 (2021)

Inhibiting Jahn–Teller distortion in Mn-based cathode







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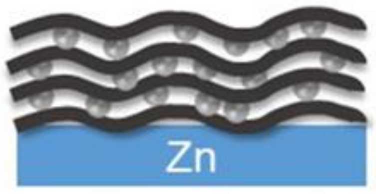
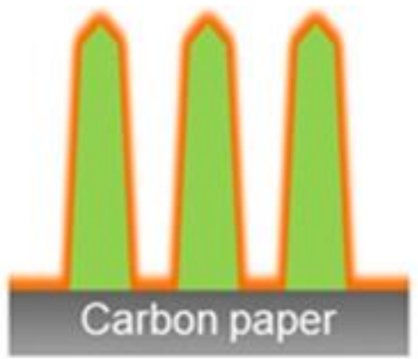
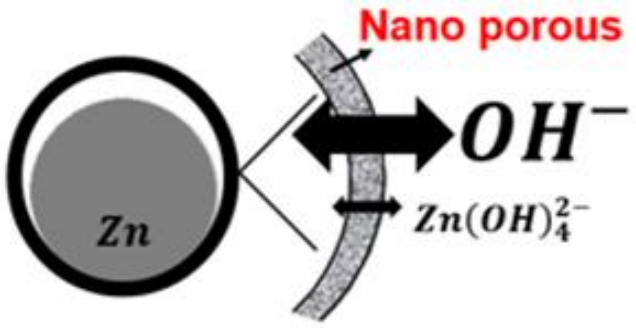
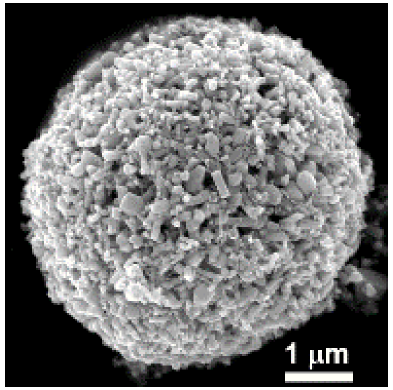
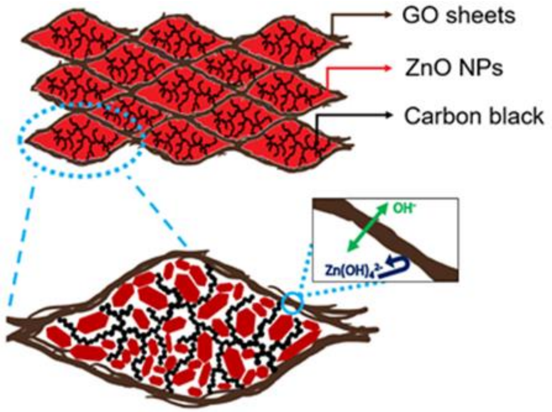
Summary: material engineering enables deeply rechargeable NiMH and Zn anodes in alkaline electrolyte











Acknowledgement

Yamin Zhang Yutong Wu Zhitao Chen

Evan Wilson Tzu-Ho Wu Huitian Liu

Yuju Jeon Peng Chen Zhubo Zhou Yu Yan

Collaborators: Prof. Joshua Howe (Texas Tech University)

Dr. Timothy Lambert (Sandia National Labs)

Sponsors of this research:

Lynntech

GP Batteries