$Na-O_2$ Batteries: Steps Toward Reality

— Artificial Protected Na Anode in $Na-O_2$ Batteries

Name: Xiaoting Lin
Supervisor: Prof. Andy Sun
Program: $Na-O_2$ battery
Level of studies: Ph.D.
Presentation Date: April 30, 2020

Na-O_2 batteries: Steps Toward Reality

- **Na–O_2 batteries**
  - ✓ High theoretical energy density (6-9 times higher than Li-ion battery)
  - ✓ High energy efficiency
  - ✓ Low cost and abundance of Na
  - × Poor cycle life

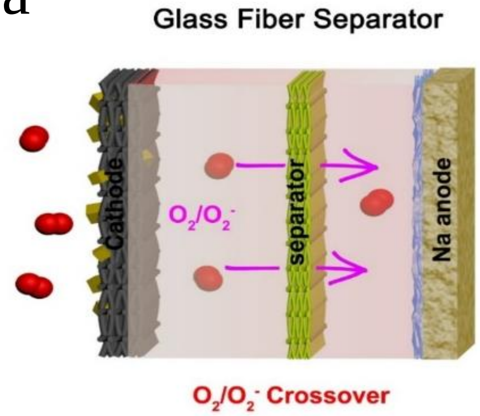
- **Challenges of Na anode in Na-O_2 batteries**
  - ❖ The Na degradation associated with O_2/O_2^- crossover

    Induce serious side reactions on Na metal anode, side products accumulation will imped the Na^+ transport. (Fig. a)
  - ❖ The uncontrollable Na dendrite growth

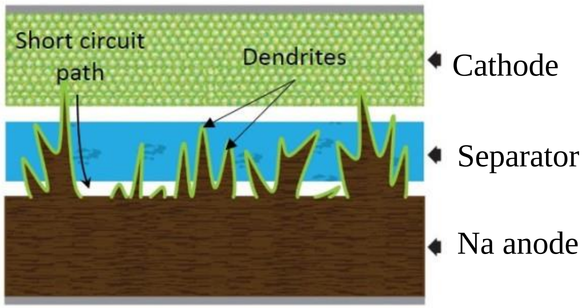
    Cause internal short circuit or even safety concerns. (Fig. b)

Introducing artificial Na protective layer is a typical approach to suppress Na dendrite growth in Na-ion batteries, while the electrochemical behavior of protected Na anode in Na-O_2 batteries is unclear.

a



b



Objective(s)

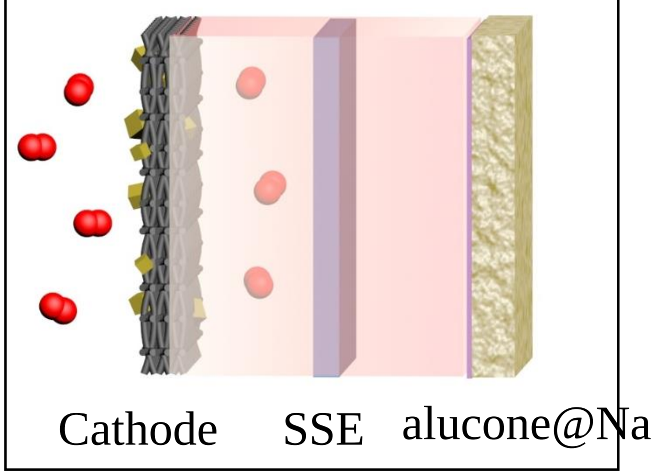
1. Investigate the cycling stability of alucone layer protected Na anode (alucone@Na) in Na-O_2 batteries.
2. Achieve high-capacity and long-life Na-O_2 batteries.

Tasks/Plan

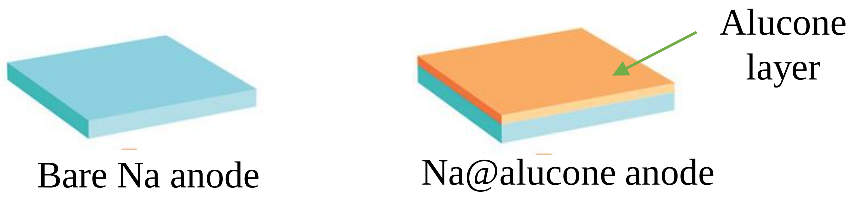
1. Prepare the alucone@Na anode using the atomic layer deposition method.
2. Synthesize the NASICON-type solid-state electrolyte (SSE).
3. Investigate the discharge/charge behavior of Na-O_2 cells with different configurations.

Expected Outcome & Deliverables

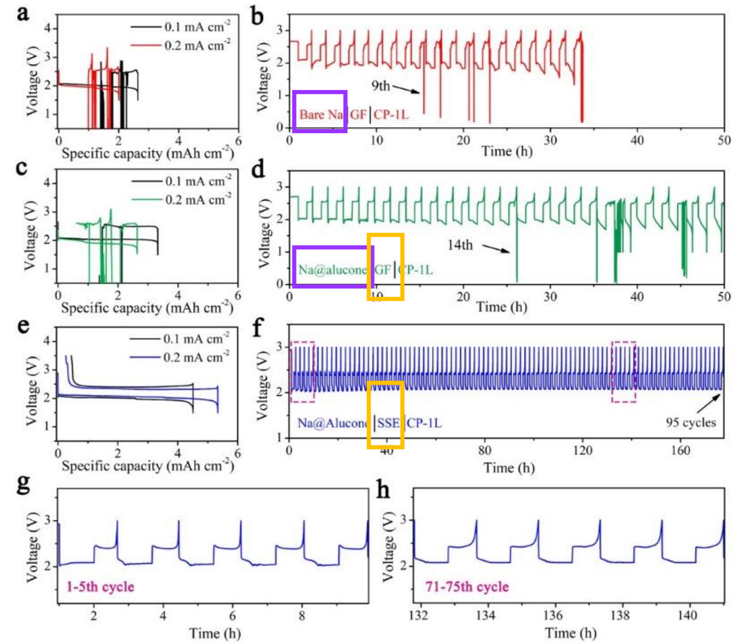
- The electrochemical behavior of alucone@Na anode can be revealed, and the cycle life of Na-O_2 batteries can be significantly increased.
- One peer-reviewed journal paper



Progress Report-1



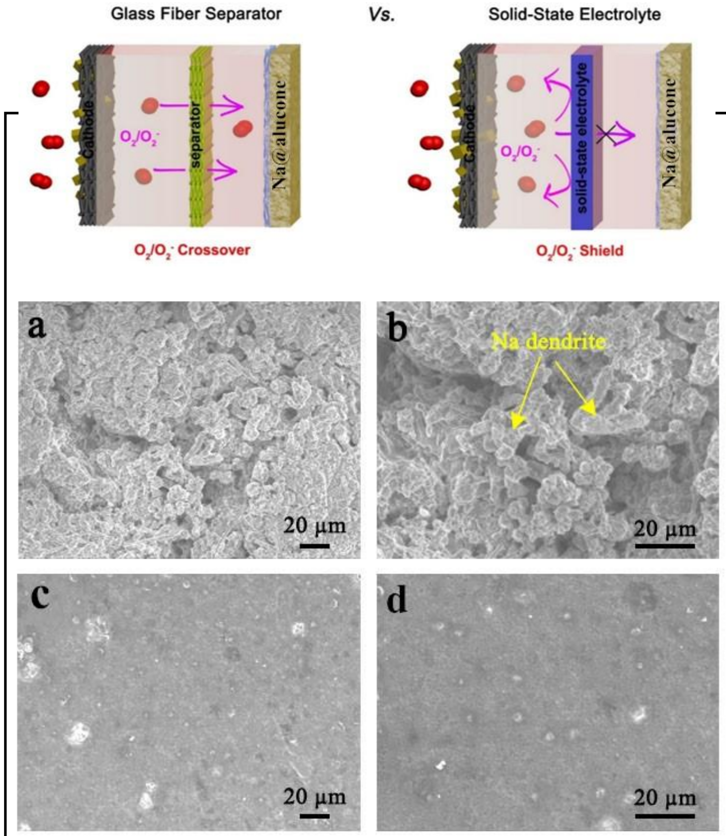
- Na@alucone anode exhibit no obvious improvement over the bare Na anode in terms of electrochemical performance. (Fig. a-d)
  (in sharp contrast to its stable performance in Na-ion batteries)
- Distinct behaviors of Na@alucone anode in Na-ion and Na-O_2 cells can be possibly related to their different working chemistries. (O_2/O_2^- crossover)
- After eliminating O_2^- crossover effect towards Na@alucone anode with SSE, the organic alucone coating retrieved its Na dendrite suppressing effect. (Fig. e)
- The cycle life of hybrid solid-state Na-O_2 cells can be significantly improved compared with traditional Na-O_2 batteries. (Fig. f-h)
- The alucone protective layer is sensitive to the attack of O_2^-, and thus lose its protective effect.



(a, b) Na-O_2 cells with GF separator and bare Na anode, (c, d) Na-O_2 cells with GF separator and Na@alucone anode, and (e, f) HSS Na-O_2 cells with SSE and Na@alucone anode. (g, h) Discharge/ charge profiles of HSS Na-O_2 cell at selected cycles.

Progress Report-1

- Na dendrites of approximately 10-20 μm can be clearly observed on the cycled Na@alucone anode in the presence of O_2^- crossover. (Fig. a, b)
- The formation of porous layer indicate the destruction of protective alucone film on Na metal anode under O_2^- crossover effect.
- Relatively smooth surface without dendritic Na or unfavorable porous layer can be observed on the Na@alucone electrode after introducing SSE. (Fig. c, d)
- The shielding effect of SSE against O_2^- crossover restore the dendrite suppressing function of alucone on Na metal anode.
- The combination of SSE and Na@alucone anode can address the Na dendrite growth and O_2/O_2^- crossover issue comprehensively.



(a, b) Top-view SEM images of the Na@alucone anode obtained from cycled Na-O_2 cell with glass fiber separator; (c, d) Top-view SEM images of the Na@alucone anode obtained from cycled Na-O_2 cell with solid-state electrolyte.

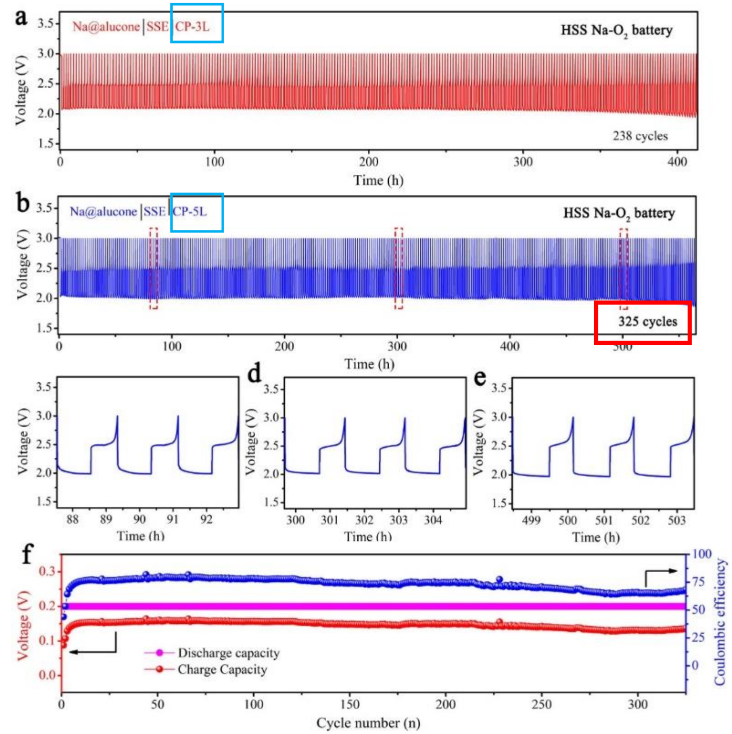
Progress Report

- The cycle life of Na-O_2 cells enhance with increasing the cathode loading, which is related to the increase of active sites. (Fig. a, b)

- Coverage of active sites by the insulating side products results in the decrease of Coulombic efficiency upon cycling. (Fig. f)

- The synergistic protective effect of SSE and Na@alucone anode enables long-term cycling of Na-O_2 batteries at 0.2 mA cm^{-2} with a cutoff capacity of 0.2 mAh cm^{-2}.

- The stability of Na protection layer and the issues involving the high reactive O_2^- radicals should be considered seriously in the future study of Na-O_2 batteries.



Cycling performance of HSS Na-O_2 cells with (a) CP-3L cathode and (b) CP-5L cathode; (c-e) selected discharge/charge profiles of HSS Na-O_2 cell with CP-5L cathode; (f) The cycling properties and Coulombic efficiency of HSS Na-O_2 cell with CP-5L cathode.

Xiaoting Lin, Xueliang Sun*, To be submitted

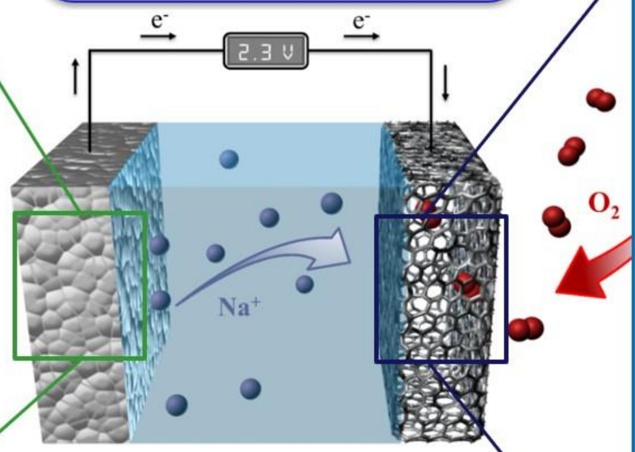
Our work on Na-O_2 batteries

Mechanism:

- H. Yadegari, X. Sun, ***J. Phys. Chem. Lett.,*** 2017, 8, 4794.
- M. N. Banis, X. Sun, ***Energy Environ. Sci.***, 2018, 11, 2073-2077.

Na anode:

- Y. Zhao, X. Sun, ***Small***, 2018, 170371
- Y. Zhao, X. Sun, ***Adv. Mater.,*** 2017, 29, 160666
- Y. Zhao, X. Sun, ***Nano Lett.,*** 2017, 17, 5653
- Y. Zhao, X. Sun, ***Energy Environ. Sci.*** 11 (10), 2673-2695.
- Y. ZHao., X. Sun, ***J. Mater. Chem. A***, 7 (8), 4119-4125.
- **X. Lin,** X. Sun, ***Adv. Funct. Mater***. 2018, 1801904.
- **X. Lin**, X. Sun, ***Adv. Energy Mater.***, to be submitted.



Cathode:

- Y. Li, X. Sun, ***Chemical Communications***, 2013, 49, 11731
- H. Yadegari, X. Sun, ***Energy Environ. Sci., 2014,*** 7, 3747
- H. Yadegari, X. Sun, ***Chem. Mater.,*** 2015, 27, 3040
- Q. Sun, X. Sun, ***J. Phys. Chem. C,*** 2015, 119, 13433
- Q. Sun, X. Sun, ***Nano Energy,*** 2015, 12, 698
- H. Yadegari, X. Sun, ***Energy Environ. Sci.,*** 2017, 10, 286
- Q. Sun, X. Sun, ***Adv. Funct. Mater.*** 2017, 27, 1606662
- Q. Sun, X. Sun, ***J. Mater. Chem. A,*** 2018, 6, 1473
- M. N. Banis, H. Yadegari, X. Sun, ***Energy Environ. Sci.,*** 2018, 11, 2073-2077
- H. Yadegari, X. Sun, ***Chem. Mater.*** 2018, 30, 5156−5160
- **X. Lin,** X. Sun, ***Chem. Mater.,*** 2019, 31, 9024-9031.
- **X. Lin**, X. Sun, ***Chem. Mater.***, 2020, 32, 7, 3018-3027.

Review Papwe:

H. Yadegari, Q. Sun, X. Sun, ***Adv. Mater.,*** 2016, 28, 7065
H. Yadegari, X. Sun, ***Acc. Chem. Res.*** 2018, 51, 1532−1540.
X. Lin, X. Sun, ***Carbon Energy***, 2019; 1: 141-164
H. Yadegari, X. Sun, ***Trends in Chemistry***, 2020, 2, 241-253.

Thanks for your attention!