Liquid Aluminum Alloy as Anode for Redox Flow Batteries

Jorge A. Soto Puente, Shumin Li, Li Tan* (ltan4@unl.edu)
Department of Mechanical & Materials Engineering, University of Nebraska-Lincoln

Introduction

Aluminum batteries offer the possibilities of low cost, low flammability, high capacity alternative to energy storage because of its three-electron redox properties. However, the challenging issues regarding the Al anode include limited charge mobility or capacity due to the native oxide layer and easy reaction with humid air and oxygen. In this work, the Al anode is replaced by a liquid Al anode offering possibility for redox flow battery mechanisms (flowable anode and electrolyte).

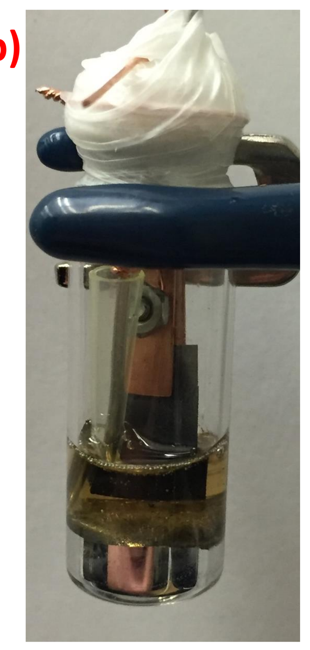
(a)

	Specific Volumetric capacity (Ah/cm³)	Specific Gravimetric capacity (Ah/g)
Aluminum	8.04	2.98
Zinc	5.85	0.82
Magnesium	3.83	2.20
Lithium	2.06	3.86

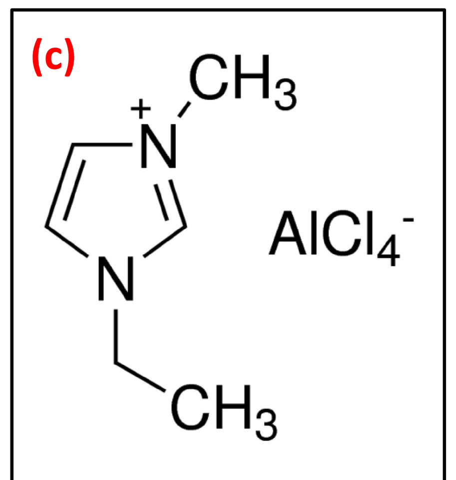
(d) Anode: $Al + 7AlCl_4^- \underset{charge}{\overset{discharge}{\rightleftharpoons}} 4Al_2Cl_7^- + 3e^-$

Cathode: $C_n[AlCl_4^-] + e^- \underset{charge}{\overset{discharge}{\rightleftharpoons}} C_n + AlCl_4^-$

(b)



(c)

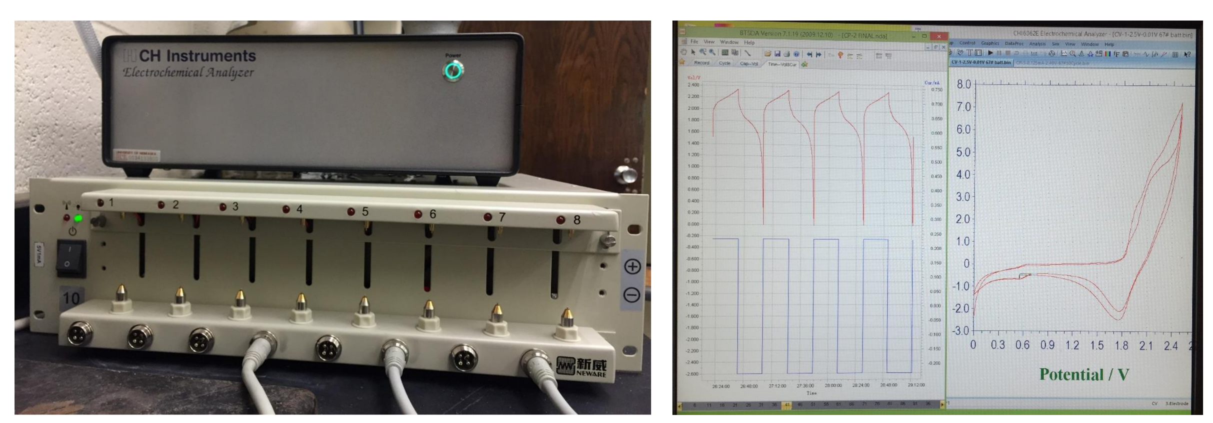


$AlCl_3$/[EMIm]Cl ionic liquid

Figure 1. Comparison of theoretical specific capacities [1] of different anode materials (a); photo of as-prepared rechargeable battery (b) using liquid Al alloy as hybrid anode and ionic liquid (c) as the electrolyte; and respective reactions [2] at the electrodes (d).

Material Preparation and Characterizations

- **Anode**: liquid Al/Gallinstan alloy
- **Electrolyte**: $AlCl_3$/[EMIm]Cl
- **Cathode**: PG (Pyrolytic Graphite) foils
- **Electrochemical tests**: CH-Instruments and Neware multi-channel battery analyzer



Results and Discussion

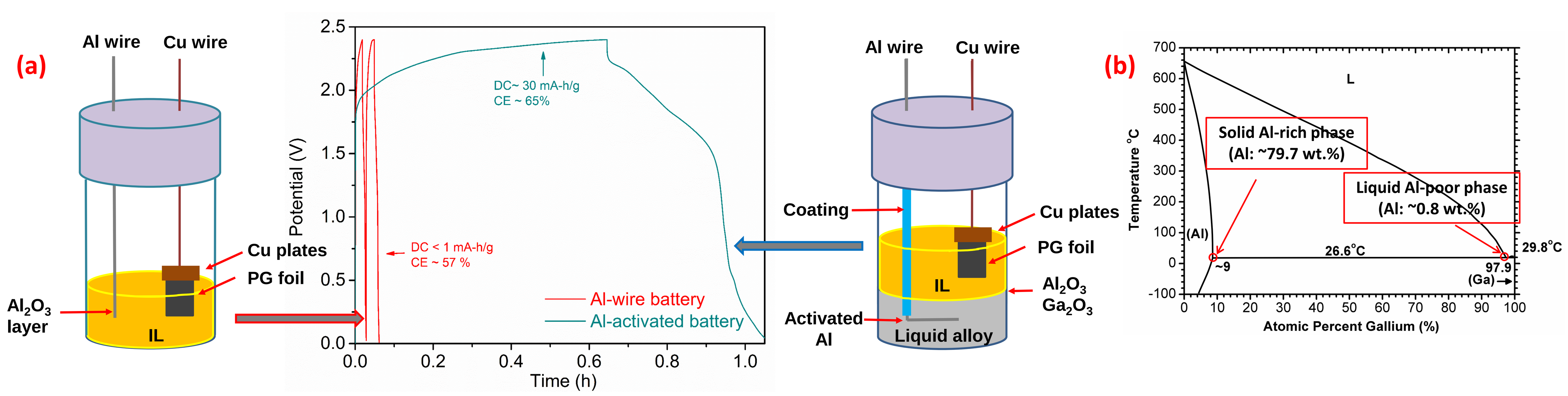


Figure 2. Charge-discharge curves of solid Al wire and liquid Al batteries (a) with discharging capacity (DC) and coulombic efficiency (CE); Al dissolved in Gallinstan can be simplified as mixing Al and Ga to form a solid Al-rich component and a liquid Al-poor component (phase diagram of Al-Ga alloy) (b).

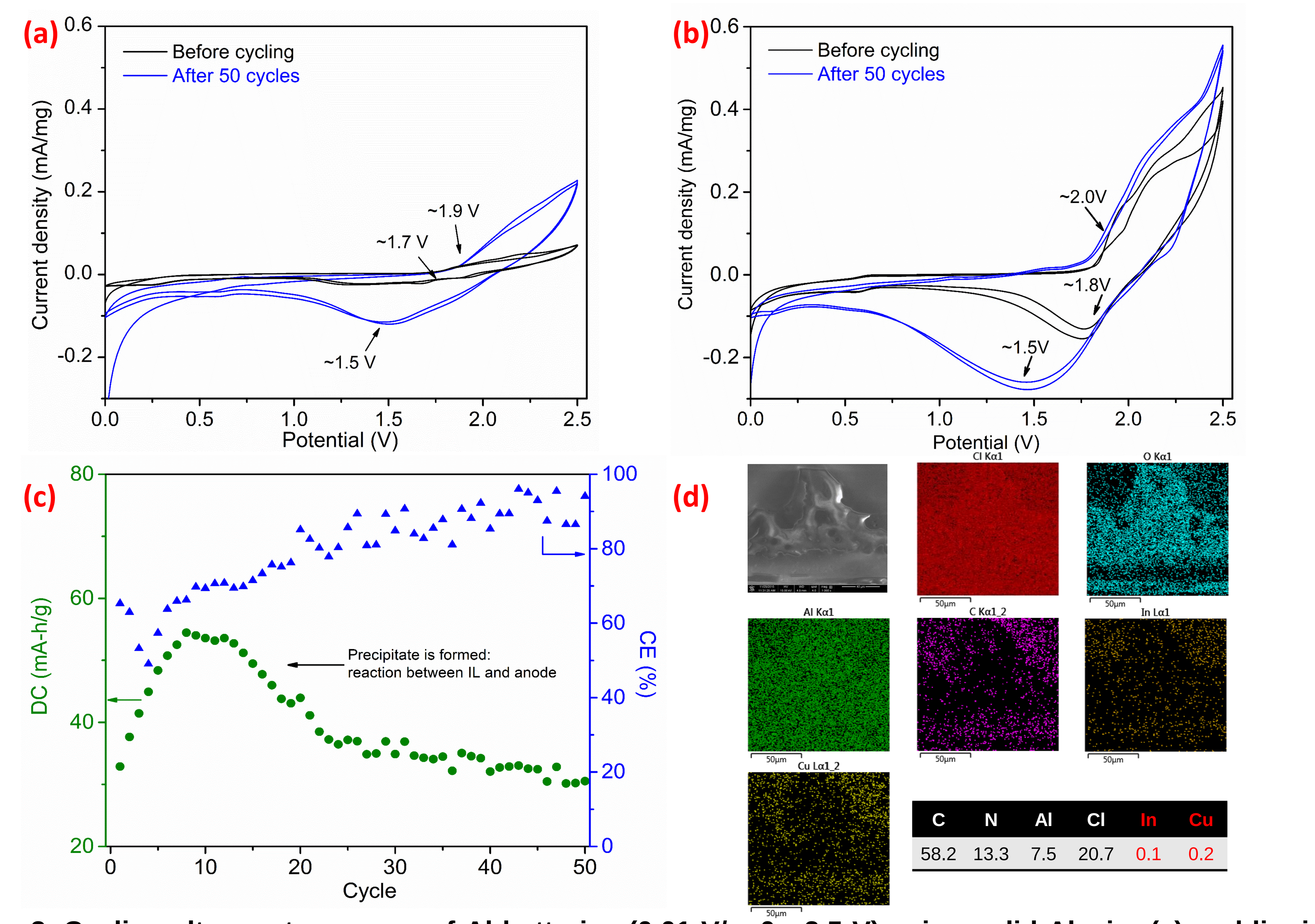


Figure 3. Cyclic voltammetry curves of Al batteries (0.01 V/s, 0 - 2.5 V) using solid Al-wire (a) and liquid Al (b) as anodes (Cu plates as current collector); DC and CE of liquid Al battery (c); EDX elementary analysis (%atom, normalized to oxygen) from precipitate (d).

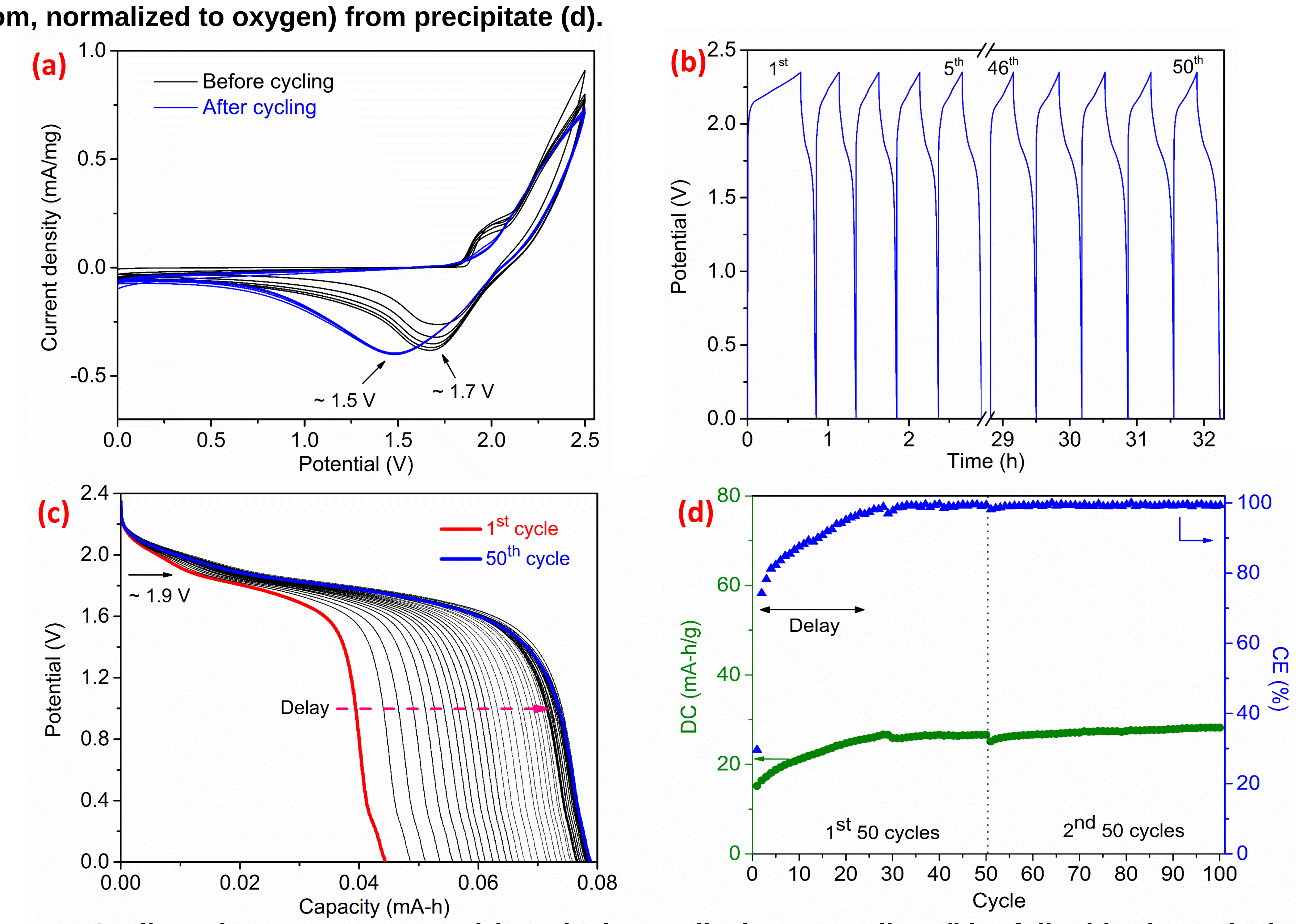


Figure 4. Cyclic voltammetry curves (a) and charge-discharge cycling (b) of liquid Al anode battery (stainless steel as current collector); evolution of discharge curve for the first 50 cycles (c); DC and CE for 100 cycles (d).

Conclusions and Future Work

- **Liquid Al anode battery offers higher DC, discharge plateau and CE compare to Al wire battery.**
- **Stable performance and CE ~ 100% was obtained by using stainless steel as current collector and highly porous PG.**
  - **Understand mechanisms for PG activation (delay).**
  - **Tune the $AlCl_3$/[EMIm]Cl ratio.**
  - **Elucidate the structure of liquid Al alloy.**

References and Acknowledgment

[1] Revel R., Audichon T., Gonzalez S., Journal of Power Sources, 2014, 272, 415-421; [2] Lin M-C, Gong M, *et al.*, *Nature*, 2015, 520, 325-328

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