



Contents lists available at ScienceDirect

Applied Energy

journal homepage: [www.elsevier.com/locate/apenergy](http://www.elsevier.com/locate/apenergy)

# A mixed-pH dual-electrolyte microfluidic aluminum–air cell with high performance <sup>☆</sup>

Binbin Chen <sup>a</sup>, Dennis Y.C. Leung <sup>a,\*</sup>, Jin Xuan <sup>a,b,c</sup>, Huizhi Wang <sup>a,b,\*</sup>

<sup>a</sup> Department of Mechanical Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong

<sup>b</sup> School of Engineering & Physical Sciences, Heriot-Watt University, Edinburgh EH14 4AS, United Kingdom

<sup>c</sup> State-Key Laboratory of Chemical Engineering, School of Mechanical and Power Engineering, East China University of Science and Technology, Shanghai 200237, China

## HIGHLIGHTS

- A mix-pH dual-electrolyte Al–air cell is proposed.
- Cells with dual-electrolyte exhibit higher performance.
- Cell performance increases with increasing electrolyte concentration and flow rate.
- Optimized channel thickness is 0.3 mm.
- A restriction of reaction activation on the Al side is observed.

## ARTICLE INFO

### Article history:

Received 4 July 2015

Received in revised form 30 September 2015

Accepted 3 October 2015

Available online xxxxx

### Keywords:

Aluminum–air cell

Co-laminar flow

Dual-electrolyte

Microfluidic

## ABSTRACT

Energy storage capacity has been a major limiting factor in pursuit of increasing functionality and mobility for portable devices. To increase capacity limits, novel battery designs with multi-electron redox couples and increased voltages have been listed as a priority research direction by the US Department of Energy. This study leverages the benefits of microfluidics technology to develop a novel mixed-pH media aluminum–air cell which incorporates the advantages of the trivalence of aluminum and mixed-pH thermodynamics. Experimentally, the new cell exhibited an open circuit potential of 2.2 V and a maximum power density of 176 mW cm<sup>-2</sup>, which are respectively 37.5% and 104.6% higher than conventional single alkaline aluminum–air cell under similar conditions. With further optimization of channel thickness, a power density of 216 mW cm<sup>-2</sup> was achieved in the present study.

© 2015 Elsevier Ltd. All rights reserved.

## 1. Introduction

Energy storage has become a growing global concern over the past decade as a result of drastic consumption of non-renewable fuels, along with increasing energy demands from daily lives and industrial manufacturing [1,2]. This calls for more efficient energy storages and power sources with higher energy densities and capacities [3].

Aluminum (Al)–air cells, working with an inexhaustible cathode reactant (i.e. oxygen from air), hold certain promise as an

alternative to existing commercial batteries because of their unsurpassable capacity and energy densities [4]. In conventional alkaline Al–air cells, Al exhibits a theoretical energy density of 8.10 W h g<sup>-1</sup> [4,5]. Compared with other active anode materials for metal–air cells, such as lithium, magnesium and zinc, Al has the highest volumetric capacity density of 8.05 A h cm<sup>-3</sup> contributed by the trivalence of aluminum ions. Additional benefits of Al are the environmental friendliness and low price [6,7]. Along with the large base of raw material reserves, Al attracts considerable interest as a promising anode material for metal–air fuel cell. In past decades, great emphasis had been focused on Al–air cells working with single alkaline or neutral brine electrolyte [8–10]. By employing polyacrylic acid–base alkaline gel electrolyte, Zhang et al. developed an all-solid-state Al–air battery with a peak capacity density of 3148 mA h cm<sup>-3</sup> and a high power density of 91.13 mW cm<sup>-2</sup> [11].

Different from single-electrolyte cell, a concept of mixed-pH dual-electrolyte design for increasing thermodynamic potential has been studied in the microfluidic H<sub>2</sub>/O<sub>2</sub> fuel cell [12], metal

<sup>☆</sup> This paper was presented at the 7th International Conference on Applied Energy (ICAE2015), March 28–31, 2015, Abu Dhabi, UAE (Original paper title: 'A high performance dual electrolyte aluminum–air cell' and Paper No.: 187).

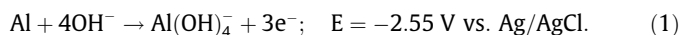
\* Corresponding authors at: Department of Mechanical Engineering, The University of Hong Kong, Hong Kong. Tel.: +852 28597911; fax: +852 28585415 (D.Y.C. Leung). School of Engineering & Physical Sciences, Heriot-Watt University, Edinburgh EH14 4AS, United Kingdom. Tel.: +44 0131 451 8354; fax: +44 0131 451 3129 (H. Wang).

E-mail addresses: [ykleung@hku.hk](mailto:ykleung@hku.hk) (D.Y.C. Leung), [h.wang@hw.ac.uk](mailto:h.wang@hw.ac.uk) (H. Wang).

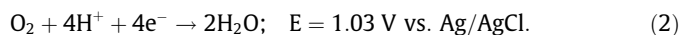
hydride/lead dioxide cell [13] and metal hydride/vanadium rechargeable battery [14]. A mixed-pH media provides different alkaline and acid environment for the anode and cathode, respectively, which could bring benefit of an increase of 50% in the open circuit potentials and power output [13]. Based on laminar flow pattern [15–17], the interface between the two electrolytes with different pH could be well maintained in a microchannel, severing as a virtual membrane to separate those electrolytes and conduct ions.[6] Without the use of physical proton-exchange membrane (PEM), this membraneless system could eliminate the intrinsic problems of PEM, such as desiccation, tearing and deterioration [18,19], and also much reduce the cell cost.

In this work, the concept of a novel mixed-pH dual-electrolyte Al–air cell, built on a Y-shape membraneless platform, is demonstrated. In this dual-electrolyte system, streams of alkaline anolyte and acidic catholyte flow separately, with minimal convective mixing, to provide different pH-media for electrodes. The half-cell reactions of the Al–air cell for different electrolytes are [11,20]:

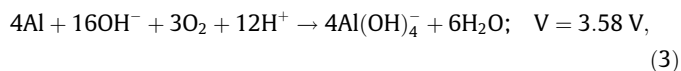
Anodic reaction in alkaline electrolyte:



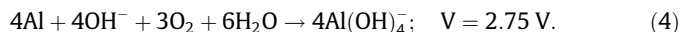
Cathodic reaction in acid electrolyte:



Overall reaction in dual-electrolyte Al–air cell system is:



Compared with that in single alkaline cell system:



The Al–air cell with dual electrolyte has a thermodynamic potential of 3.58 V which is 0.83 V higher than that of single-alkaline-electrolyte cell. The theoretical energy density considering only Al also increases from  $8.10 \text{ W h g}^{-1}$  in conventional alkaline electrolyte to  $10.54 \text{ W h g}^{-1}$  for dual-electrolyte Al–air cell. A detailed experimental comparison of the cell performance between dual- and single-electrolyte is presented in following sections. Parameters of electrolyte concentration, flow rate and channel thickness have been studied to understand the underlying mechanism. In addition, a durability test of this dual-electrolyte Al–air cell was carried out to show its long term stability in terms of current and voltage.

## 2. Experimental setup

### 2.1. Cell design and fabrication

Fig. 1 shows a schematic illustration of the Y-shape membraneless Al–air cell structure exploited in this study. The cell structure consists of three polyvinyl chloride (PVC) layers cut by carbon dioxide laser ablation system (VLS 2.30, Universal Laser System). A Y-shape channel is cut out in the middle layer, with a width of 1.5 mm in branch segment and a width of 3.0 mm in converged segment, serving as the electrolyte flowing path. The branch segment is a curved channel with inner and outer radius of 13.5 mm and 15.0 mm, respectively. This channel configuration is designed to aid in the establishment of co-laminar flow and minimizing convective mixing between catholyte and anolyte. During operation, streams of catholyte and anolyte flow through the branch segments and then form co-laminar flow in the converged segment. The thickness of the channel employed is 1 mm except for those experiments to investigate the effect of channel thickness. The bottom and top layer, with thickness of 0.1 mm, each has a rectangular window around the edge of channel cut out for the electrodes to

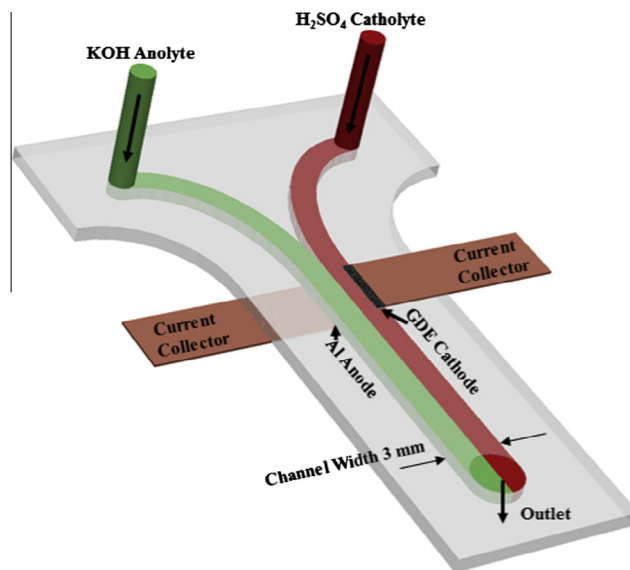


Fig. 1. Schematic illustration of Y-shape membraneless Al–air cell structure.

contact with electrolyte. The active projected electrode area is  $0.0364 \text{ cm}^2$  ( $0.07 \text{ cm} \times 0.52 \text{ cm}$ ). The top layer seals the assembly with two inlets and an outlet for fluidic electrolyte access. Three PVC layers are adhered using double-side adhesive tape. The electrolyte is pumped into the cell by a syringe pump (LSP02-1B, LongerPump) at a flow rate of  $1300 \mu\text{l min}^{-1}$ , except for the experiment to investigate the effect of flow rate, via 1.5 mm tubing bonded to the ports with quick dry epoxy.

### 2.2. Chemicals

Electrolytes of aqueous KOH and  $\text{H}_2\text{SO}_4$  solutions with different concentrations (i.e. 1 M, 2 M and 3 M) are prepared by dissolving KOH pillars ( $\geq 85\%$ , Sigma Aldrich) and  $\text{H}_2\text{SO}_4$  (95–97%, Sigma Aldrich) in 18.2 M $\Omega$  deionized water (Barnstead, NANOpure Diamond™). Al bulk with a purity of 99.9% is used as anode. The cathode is a gas diffusion electrode (GDE) from Shanghai Hesen Company. The GDE has carbon paper (HCP120, Hesen) with a microporous carbon layer as the catalyst support and gas diffusion layer. The catalyst powder, Pt/C (60 wt.% Pt, Johnson Matthey), is dispersed by dispersion solvent (ethanol and water, 1:1 volume ratio) with 5 wt% Nafion solution first. After being sonicated for 1 h, the suspension is sprayed onto the carbon paper with an overall loading of  $2 \text{ mg cm}^{-2}$  Pt/C. Copper foil is used to connect the electrodes with external circuit. The electrode and copper foil are bonded with silver glue to ensure the conductivity.

### 2.3. Cell testing

Electrochemical measurements were carried out under room temperature and ambient atmospheric pressure. The polarization curves were obtained by potentiostatic current measurement at every 0.2 V for 150 s from short circuit by a CHI 660E electrochemical workstation (Shanghai Chenhua Instruments Co., Ltd.). The average value of the current data in the last 50 s was used to represent the cell current at a certain voltage. An Ag/AgCl (Saturated KCl) electrode (Shanghai Lei-ci Co., Ltd.) was used as a reference electrode to acquire single-electrode potentials of the cell. The data were recorded *in situ* by a digital multimeter (15B, Fluke Corporation). Electrochemical impedance spectroscopy (EIS) of the dual-electrolyte Al–air cell was taken in the frequency range of 120 kHz–100 mHz, with a signal A.C. amplitude of 5 mV at

Download English Version:

<https://daneshyari.com/en/article/4917064>

Download Persian Version:

<https://daneshyari.com/article/4917064>

[Daneshyari.com](https://daneshyari.com)