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Guiding bubble motion of rechargeable zinc-air battery with electromagnetic force

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HIGHLIGHTS

- Oxygen bubbles coalescence was inhibited by the normal magnet.
- Law of bubbles movement was investigated by optical measurement.
- Control of bubbles movement was applied to rechargeable zinc-air battery.

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ABSTRACT

Rechargeable metal-air batteries will be a promising candidate for energy storage due to their high energy density. However, bubbles coalescence near the electrode blocks the following electrochemical reaction, seriously worsening the cycling performance of rechargeable zinc-air battery. Here we present control of oxygen bubbles movement with electromagnetic coupling, where a permanent magnet is placed near the electrode, and the strength of magnetic field at the electrode surface can be changed by means of spacing adjustment between the electrode and the magnet. The bubbles from oxygen evolution reaction can be quickly detached from the electrode surface under the condition of the electromagnetic field, achieving directional movement of oxygen bubbles. The results show that the electromagnetic field can inhibit bubbles coalescence, reducing phase transformation impedance and improving the performance of rechargeable zinc-air battery. The proposed solutions will be available for improving the morphology of metal electrodeposition as well as rechargeable metal-air batteries.

1. Introduction

Rechargeable zinc-air batteries can be in application of energy storage and power supply due to its higher energy density, environmental compatibility, and economic availability [1,2]. Unfortunately, the lifetime problem of rechargeable zinc-air battery is still unresolved [3,4], which is mainly subjected to morphological change of zinc electrode [5] and oxygen bubbles coalescence near the charging electrode [6]. Moreover, energy efficiency of rechargeable zinc-air battery is still low, which is mostly affected by hysteretic kinetics of oxygen redox. A variety of catalysts has been explored to reduce the charge-discharge polarization, including noble metals and their alloys, carbon nanostructure materials, transition metal oxides, and inorganic/organic compound materials [7–14].

To suppress dendrite growth of zinc electrodeposition, most of the studies were focused on the use of inorganic/organic additives to zinc electrode or the electrolyte such as bismuth trioxide, polyvinyl acetate, and triethanolamine [15–20]. However, the additive strategy would reduce either the active material of zinc electrode or the conductivity of the electrolyte, deteriorating the battery performance. Meanwhile, the rest was concentrated on operating parameters optimization to control morphological change of zinc deposits. First, the charging mode of pulse currents was used for increasing the relaxation time of ion diffusion and decreasing uneven distribution of ion concentration at electrochemical reaction sites [21–24]. Furthermore, reinforcing electrolyte hydrodynamics was applied to lower ion concentration gradient between the electrochemical electrolyte and the bulk electrolyte [25–27]. Besides, the separator was placed between the anode and the cathode to retard dendrite growth [28]. These solutions can inhibit dendrite growth of zinc deposits but reduce the performance of the battery system.

The rate of oxygen transfer has also influence on the performance of

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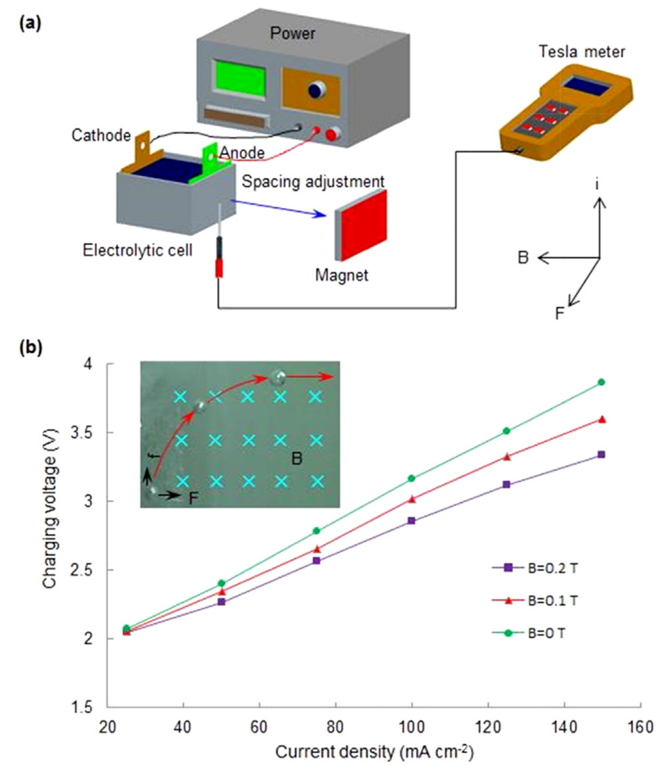

Fig. 1. (a) Schematic view of experimental set of oxygen bubbles regulation with a magnet, (b) Effect of the magnetic field on the charging voltage.

rechargeable zinc-air battery as well as morphological change of zinc electrode. Oxygen bubbles easily coalesce with each other at the electrode surface, blocking the charging and even shortening the battery's lifetime. Moreover, oxygen bubbles adhered to the electrode surface would increase the charging voltage, leading to dendrite growth of electrodeposited zinc. To solve the problem of bubbles coalescence of rechargeable zinc-air battery, electrolyte flow was usually employed to remove these bubbles [29,30], but it will increase additional energy consumption. The saline material was added in the electrolyte to inhibit bubbles coalescence [31] or the charging electrode was partially insulated to change electrochemical reaction sites [32], increasing the internal resistance of the battery.

The magnetic field was reported to promote oxygen transfer [33–35], but few were involving with rechargeable zinc-air battery. In this work, the magnetic field was used for inhibition of zinc dendrite growth and bubbles coalescence, improving the cycling performance of rechargeable zinc-air battery.

2. Experimental

2.1. Bubbles movement testing

The experiment of oxygen evolution reaction was conducted in the electrolytic cell (200 mm × 50 mm × 50 mm) at normal temperature and pressure, where the anode was fabricated by the nickel mesh (surface size of 40 mm × 40 mm, pore size of 3 mm × 2 mm, wire diameter of 0.7 mm), the cathode was made of the stainless steel (surface size of 40 mm × 40 mm, thickness of 1.5 mm), and the electrolyte was prepared by potassium hydroxide (30 wt%), the deionized water (70 wt%) and zinc oxide (0.6 mol L^{-1}). In view of oxygen bubbles movement and non-Faradic reaction of zinc electrodeposition, the charging current of 100 mA cm^{-2} was used and the permanent magnet

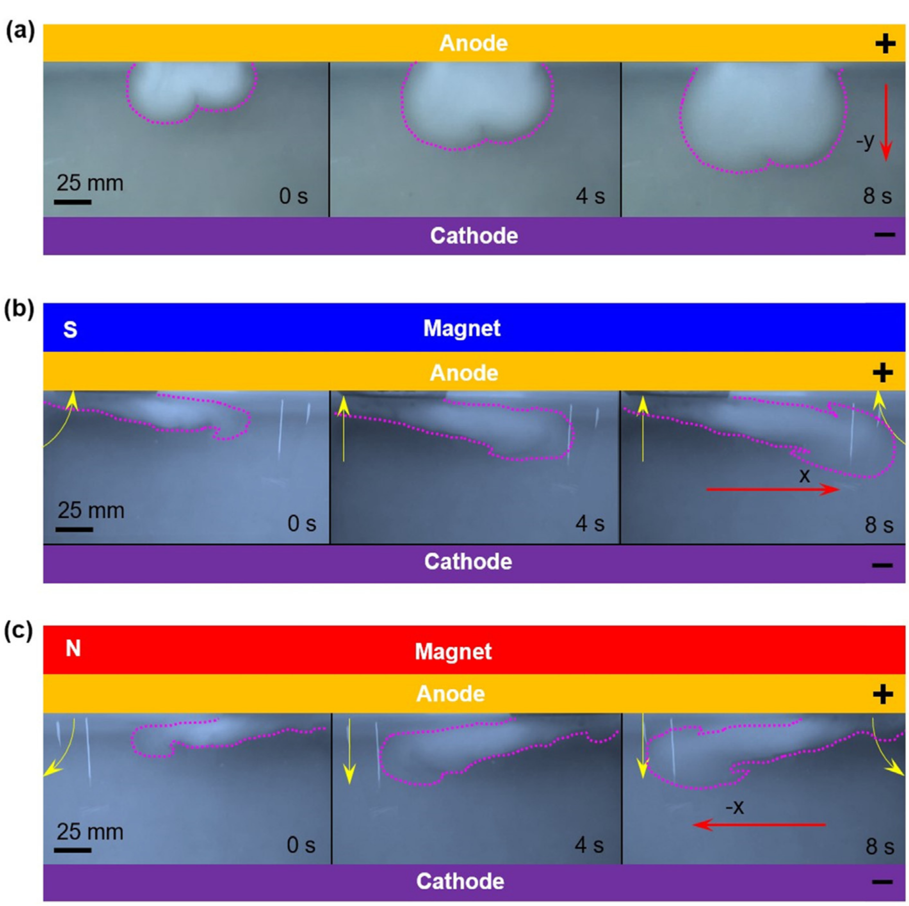

Fig. 2. Directional movement of oxygen bubbles, (a) Without the magnet, (b) S pole of the magnet towards the electrode, and (c) N pole of the magnet towards the electrode. (Red arrow represents movement direction of oxygen bubbles, and yellow arrows are the direction of magnetic field). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)