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Liquid exfoliation graphene sheets as catalysts for hybrid sodium-air cells

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ABSTRACT

Graphene sheets are prepared by subjecting pyrolytic graphite in acetone to liquid exfoliation with sonication. Pyrolytic graphite is synthesized via arc discharge method. Five-layered graphene sheets are obtained through sonication for 12 h. The synthesized graphene sheets are then used as catalysts for hybrid sodium-air cells. The electrocatalytic activity of the exfoliated graphene sheets toward oxygen reduction reaction (ORR) is higher than that of pyrolytic graphite because of numerous edges and efficient electron communication between active edge sites and electrode substrate in the former. The discharge voltage is held constant at 2.48 V versus Na/Na^+ for the exfoliated graphene sheets as the catalyst at a current density of 1 mA cm^{-2} and room temperature.

1. Introduction

Liquid exfoliation is a simple method to prepare graphene sheets by introducing additional external forces to overcome the strong van der Waals interactions between layers [1]. Sonication is commonly used to exfoliate precursors, such as graphite oxide and graphite. Graphene sheets can be exfoliated in a mixture of water and acetone through sonication; thus, graphene dispersions are produced at a high concentration of 0.21 mg ml^{-1} [2].

Graphene and graphene-based materials have shown great potential in energy storage and conversion [3]. Defect-introduced graphene sheets with porous structures are initially fabricated as the anode of lithium-ion batteries; thus, the first reversible specific capacity reaches as high as 1009 mA h g^{-1} [4]. As cathodes, nitrogen-doped graphene nanosheets (GNS) are selected for high-capacity and non-aqueous sodium-air batteries with a discharge capacity of twice that of their pure counterparts [5]. Hybrid sodium-air has also been extensively investigated, comparing with nonaqueous sodium-air cell, it avoids gas-permeable electrode clogging, and it is less sensitive and more robust in certain atmospheres [6–10]. However, most of previous researchers focus on using noble metals as catalysts for sodium-air cell; using graphene sheets as a catalyst for hybrid sodium-air cells has yet to be described.

In this work, pyrolytic graphite was prepared as a precursor via arc discharge method and used to prepare graphene sheets through liquid exfoliation in acetone. The layer of graphene sheets was controlled within sonication period. The obtained graphene sheets were then utilized as catalysts for hybrid sodium-air cells. Thus, excellent discharge properties were achieved.

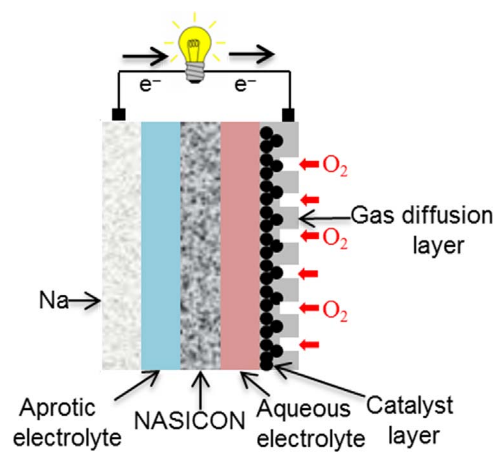

Fig. 1. Schematic of hybrid sodium-air cell.

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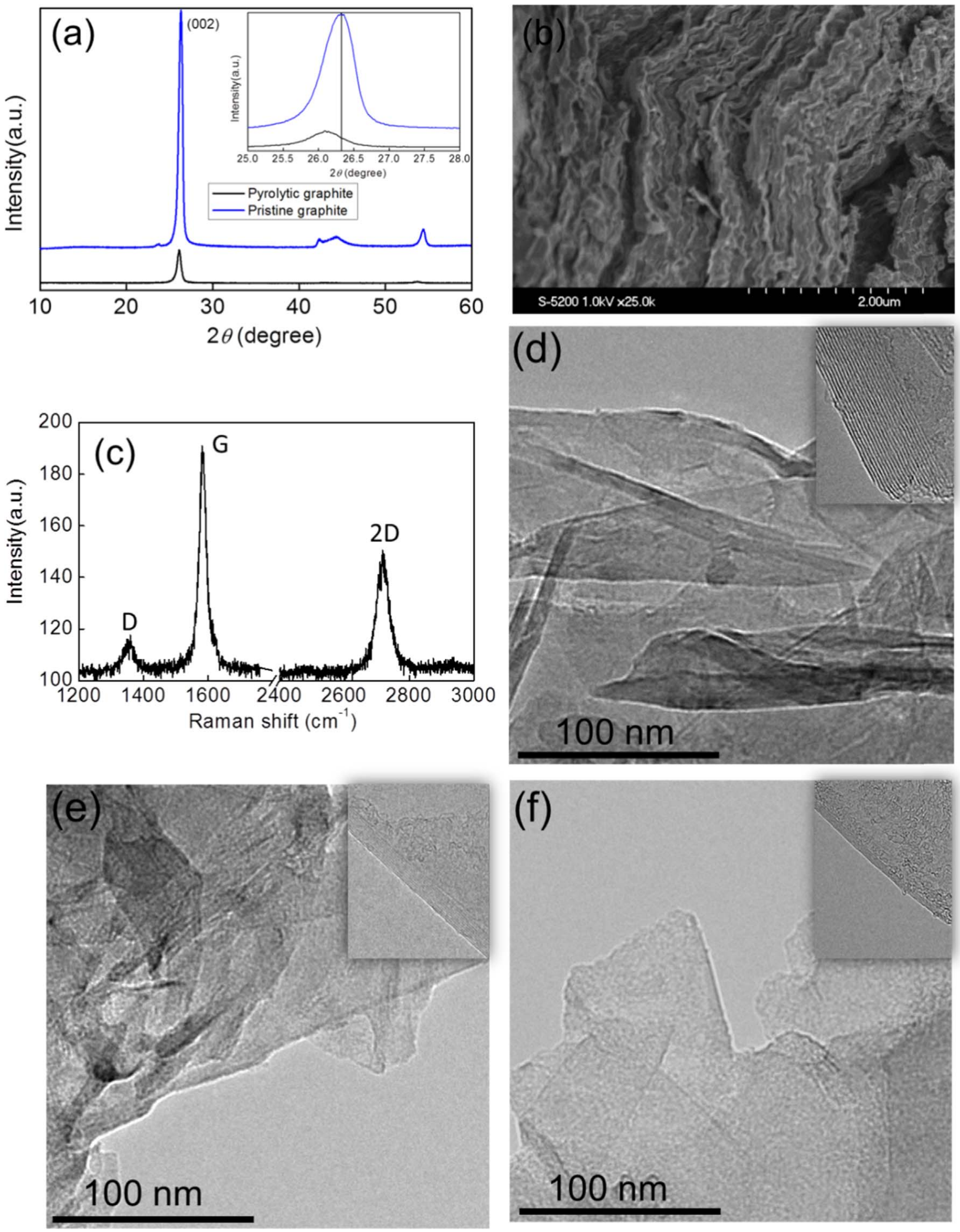

Fig. 2. (a) Comparison of XRD patterns between pristine graphite and as-prepared pyrolytic graphite (Inset: magnified XRD spectra between 25° and 28°); (b) FE-SEM image of pyrolytic graphite; (c) Raman spectrum of pyrolytic graphite; (d) TEM images of pyrolytic graphite; (e) graphene sheets subjected to sonication for 8 h; (f) graphene sheets subjected to sonication for 12 h (Inset: selected HRTEM image).

2. Experimental

Pyrolytic graphite was deposited on the graphitic anode at temperatures ranging from 2400 K to 2600 K via arc discharge method at the arc current of 200 A and arc voltage of 25.8 V [11], and it was used as the precursor to prepare graphene sheets by sonication. 0.1 mg synthesized pyrolytic graphite was ground with a mortar and pestle with 5 min. Two pyrolytic graphite samples were added to a sealed plastic bottle with 20 ml of acetone and sonicated in an ultrasonic bath (US-150T, Nihonseiki Kaisya Ltd, 19.5 kHz, 150 W) for 8 and 12 h, respectively. Exfoliated graphene sheets sonicated by 8 h and 12 h were labeled as EGS-8 and EGS-12, respectively. The sealed plastic bottle was fixed at the same position in the sonic bath during the experiment. Bathwater was continuously refilled to maintain the sonication efficiency and prevent overheating. Graphene sheets were obtained by drying the as prepared graphene suspensions at room temperature.

The prepared graphene sheets were used as catalysts for sodium-air cells. Fig. 1 shows a schematic of the hybrid sodium-air cell used in this