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Porous reduced graphene oxide sheet wrapped silicon composite fabricated by steam etching for lithium-ion battery application

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HIGHLIGHTS

- A novel preparation method is fabricated by steam etching of Si/rGO aerogel.
- This method is easy to handle and exhibited excellent performances.
- The in-situ TEM verifies the well-retained integrity of electrode in the substrate.

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ABSTRACT

A novel of Si/porous reduced graphene oxide (rGO) composite is fabricated by steam etching of Si/rGO aerogel. The rGO sheets with nano-holes build a unique three-dimensional porous network and can encapsulate the Si nanoparticles. The porous structure of Si/rGO composite can reduce the transfer distance of Li ions and restrain the aggregation and destruction of Si particles. The in-situ transmission electron microscopy (TEM) observation demonstrates that the porous rGO sheets help the entire electrode to maintain highly conductive and facilitate the lithiation of Si nanoparticles. The composite electrode presents high specific capacity and good cycling stability (1004 mAh g^{-1} at 50 mA g^{-1} up to 100 cycles).

1. Introduction

Lithium ion batteries (LiBs) are the important power source in different fields, including electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) [1,2]. High energy and power density, and excellent cycling stability are factors for the applications of LIBs. However, to meet these demands, the high capacity anode materials, such as transition metal oxides and phosphides [3–6], tin alloys and oxides [7,8], and silicon [9–11], have been studied to substitute commercial graphite with low theoretical specific capacity (372 mAh g^{-1}) [12,13]. Among these anode materials, Si is the most promising alternative because of its low cost, natural abundance and especially its highest theoretical capacity (4200 mAh g^{-1}, corresponding to the $Li_{22}Si_5$ alloy at room temperature) with a low potential window [14,15]. However, due to its low intrinsic electrical conductivity (1.56×10^{-3} S m^{-1}) and large volume change (>300%), Si suffers from limited cycling stability during the charge/discharge process [16,17].

In order to overcome these problems, the most usual approach is to prepare composites with Si nanoparticles dispersed uniformly in a carbonaceous matrix [18,19]. Graphene, a two-dimensional carbon nano-material, has a potential application for energy storage due to its large surface area, excellent conductivity, flexibility and chemical stability [20–22]. The reduced graphene oxide (rGO) as an active matrix can improve the electrochemical performance of Si-based materials [1,23,24]. The improved electrochemical performance can be

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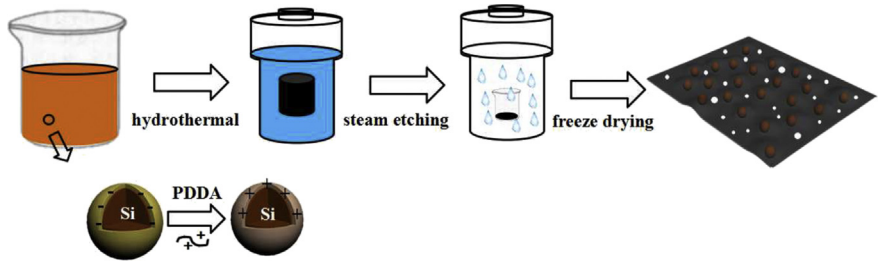

Scheme 1. Schematic of the synthesis procedure of Si/rGP.

attributed to the fact that rGO can not only enhance the electrical conductivity of Si and provide a support for dispersing Si nanostructures, but also effectively release the volume change and aggregation of Si nanoparticles during the charge/discharge process.

In this present work, we fabricated a Si/rGO nano-porous network composite (Si/rGP) anode material by simple steam etching Si/rGO aerogel. The stable porous network structure with high specific surface area is capable to reduce the transfer resistance of Li ions, and the Si/rGP composite electrode exhibits the improved reversible capacity and cycling performance. The facile method provides a new approach for the Si-based anode materials for LIBs.

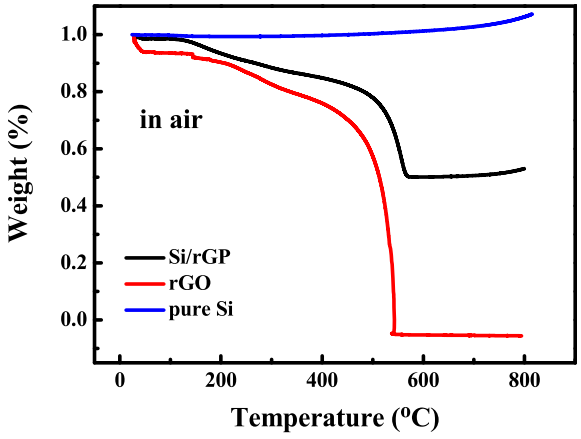

Fig. 1. TG curves of Si/rGP, rGO and pure Si in air at a heating rate of 5 °C min^{-1}.

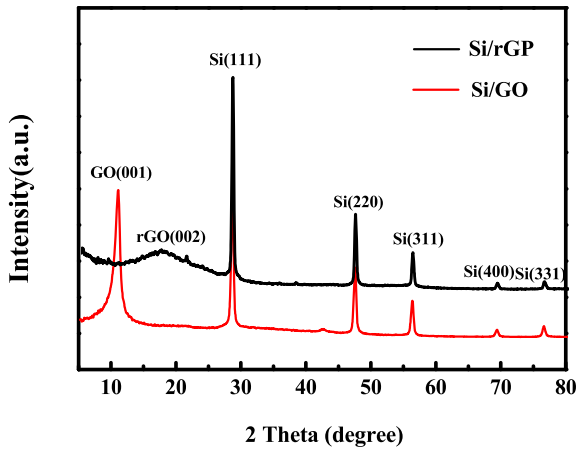

Fig. 2. XRD patterns of Si/GO and Si/rGP powders.

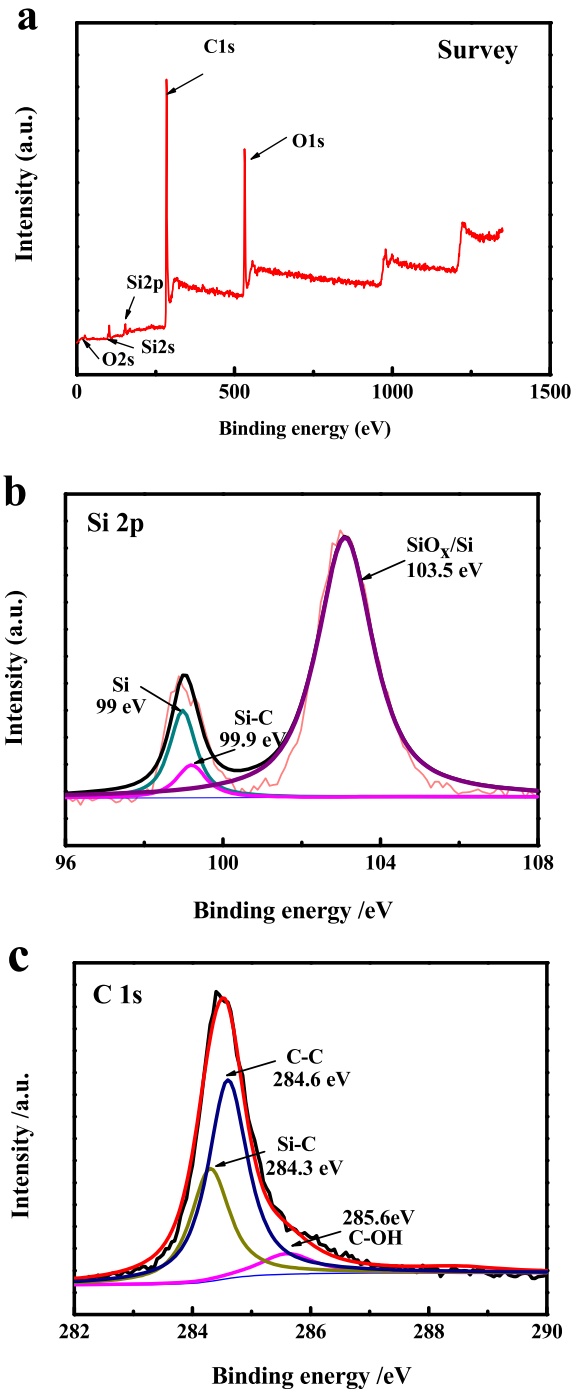

Fig. 3. XPS spectra of Si/rGP: (a) survey scan, (b) Si2p region of Si/rGP, (c) C 1s curve of Si/rGP.