ELECTRODE MATERIALS FOR RECHARGEABLE LITHIUM AND SODIUM BATTERIES

A thesis presented for the award of the degree of doctor of philosophy

By

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Certificate of original authorship

This thesis is the result of a research candidature conducted jointly with another University as part of a collaborative Doctoral degree. I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as part of the collaborative doctoral degree and/or fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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15 December 2016

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List of abbreviations

Abbreviation	Full name
a.u.	arbitrary unit
BET	Brunauer, Emmett and Teller
CF	carbon fiber
CMC	carboxymethyl cellulose
DMC	dimethyl carbonate
DME	1,2-dimethoxyethane
DMF	N,N-Dimethylformamide
DOL	1,3-dioxolane
EIS	electrochemical impedance spectroscopy
EC	ethylene carbonate
FEC	fluoroethylene carbonate
FESEM	field emission scanning electron microscopy
GO	graphene oxide
JCPDS	Joint Committee On Powder Diffraction Standards
NMP	1-methyl-2-pyrrolidinone
PAN	polyacrylonitrile
PVA	polyvinyl alcohol
PVDF	polyvinylidene fluoride
RGO	reduced graphene oxide
SEI	solid electrolyte interphase
SEM	scanning electron microscopy
TEM	transmission electron microscopy
TGA	thermogravimetric analysis
USABC	United States Advanced Battery Consortium
VC	vinylene carbonate
XRD	X-ray diffraction

Abstract

The development of lithium-ion batteries with higher power, higher energy, longer cycle life and lower cost is the focus of battery research at present, and the situation will remain the same in the foreseeable future. The research of rechargeable batteries may lead to better understanding on interfacial chemistries, the discovery of new battery chemistries and ultimately more powerful energy storage systems. This project aims at the application of carbon based composite materials as electrode materials in rechargeable lithium or sodium batteries and potential improvement in the performance of batteries via novel design of electrode materials. The electrospinning technique, microwave-assisted solvothermal synthesis process and inert gas thermal treatment have been utilized for material preparations. A series of experiments were designed to screen the most important factors that dominates the structural features of electrospun polymer fibers. One-dimensional carbon fibers and composite materials with desired structural features have been synthesized. The carbon fiber converted from electrospun polyacrylonitrile membranes are used as negative electrode materials in lithium and sodium cells, which showed stable reversible capacities of 118 mAh/g and 84 mAh/g for lithium and sodium, respectively. The antimony-carbon fiber composite materials were synthesized as alloy type negative electrodes for lithium-ion and sodium-ion batteries. The obtained material exhibited high reversible capacities of 562 mAh/g and 371 mAh/g in lithium and sodium cells, respectively. Due to the homogeneous distribution of nanosized antimony particles within the interconnected carbon fiber networks, this materials also exhibited good rate capabilities in sodium cells as it cycled at high current rates up to 1000 mA/g without severe capacity fading. The binder-free carbon electrode was used for the synthesis of composite sulfur cathode in a novel lithium-sulfur cell design, the resulted lithium-sulfur battery demonstrated a high reversible capacity of 1101 mAh/g at a high charge-discharge current of 1000 mA/g. In addition, a two dimensional graphene-based composite material containing antimony sulfide nanoparticles synthesized via microwave-assisted solvothermal approach was also investigated as potential negative electrode materials for rechargeable lithium or sodium batteries. High reversible capacities of 595 mAh/g in lithium cells and 560 mAh/g in sodium cells from this electrode materials were achieved. The material design with graphene nanosheets as the conductive substrate was proved effective for high rate charge-discharge as this composite material showed good rate capabilities under various current rates up to 1000 mA/g.