NOVEL NANOMATERIALS FOR LITHIUM ION BATTERIES AND LITHIUM SULFUR BATTERIES

A thesis presented for the award of the degree of

Doctor of Philosophy

From

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Faculty of Science

By Shuangqiang Chen, B. Sc., M. Eng.

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DEDICATION

This thesis is dedicated to my beloved wife, my parents, my brother and sister. With your concerns and helps, I have sufficient energy and strengths to fulfill my PhD research.

CERTIFICATION

I, Shuangqiang Chen, declare 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 fully acknowledged within the text.

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

Signature of student

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26-09-2014

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Professor Guoxiu Wang

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LIST OF ABBRIEVIATIONS

Abbreviation	Full name
a.u.	Arbitrary unit
BET	Brunauer Emmett Teller
C rate	Current rate
CB	Carbon black
cm	Centimeter
EIS	Electrochemical impedance spectroscopy
EC	Ethylene carbonate
Eq.	Equation
FESEM	Field emission scanning electron microscopy
FT-IR	Fourier transform inferior red spectroscopy
EV	Electric vehicle
HEV	Hybrid electric vehicle
JCPDS	Joint committee on powder diffraction standards
nm	Nanometer
NMP	1-methyl-2-pyrrolidinone
PC	Propylene carbonate
PTFE	Polytetrafluoroethylene
PVDF	Polyvinylidene fluoride
SAED	Selected area electron diffraction
SEI	Solid electrolyte interphase
SEM	Scanning electron microscopy
TEM	Transmission electron microscopy
TGA	Thermogravimetric analysis
XRD	X-ray diffraction

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ABSTRACT

Rechargeable energy storage devices are being seen as having a crucial role in the powering of myriad portable electronic devices, electrical vehicles and hybrid electrical vehicles. The properties of electrode materials are of extreme significance for the electrochemical performances of both lithium-ion (Li-ion) batteries and lithium-sulfur (Li-S) batteries.

Tin-graphene nanocomposites were prepared by a combination of microwave hydrothermal and one-step hydrogen gas reduction. When applied as an anode material in Li-ion batteries, tin-graphene nanocomposite exhibited a high lithium storage capacity of 1407 mAh g^{-1}. The materials also demonstrated an excellent high rate capacity and a stable cycle performance. Graphene-carbon nanotube hybrid materials were successfully prepared that demonstrated high reversible lithium storage capacity, high Coulombic efficiency and excellent cyclability. Fe_2O_3-CNT-graphene nanosheet hybrid materials were synthesized using a chemical vapor deposition method, exhibiting a high specific capacity of 984 mAh·g^{-1} with a superior cycling stability and high rate capabilities.

High quality single crystalline graphene sheets were prepared by the ambient pressure chemical vapor deposition method using acetylene as the carbon source and coral-like iron with body-centered-cubic structure as the catalyst. It showed high lithium storage capacity and excellent cyclability. Hierarchical three-dimensional carbon-coated mesoporous Si nanospheres@graphene foam nanoarchitectures were successfully synthesized by a thermal bubble ejection assisted chemical-vapor-deposition and magnesiothermic reduction method. The materials exhibited superior electrochemical performances, including a high specific capacity of 1200 mAh/g at the current density of 1 A/g, excellent high rate capabilities and outstanding cyclability.

Mesoporous Co_3O_4 nanoflakes with interconnected architecture were successfully synthesized by means of a microwave-assisted hydrothermal and low-temperature conversion method. Co_3O_4 nanoflakes delivered a high specific capacity of 883 mAh/g at 0.1 C current rate and stable cycling performances even at higher current rates as anodes of Li-ion batteries.

The synthesis of graphitic hyperbranched hollow carbon nanorods encapsulated sulfur composites were employed as cathode materials for Li-S batteries. The sulfur composite

cathodes delivered a high specific capacity of 1378 mAh/g at 0.1 C current rate and exhibited a stable cycling performance.

Multi-shelled hollow carbon nanospheres-sulfur composites with a high percentage of sulfur loading (86 wt. %) were synthesized by an aqueous emulsion approach and *in-situ* sulfur impregnation, delivering a high specific capacity of 1350 mAh/g and excellent capacity retention. By adopting a dual confinement strategy, poly(3,4-ethylenedioxythiophene) (PEDOT) coated micro/mesoporous carbon nanocube encapsulated sulfur (P@CNC-S) composites were synthesized. The P@CNC-S composites exhibited superior performances, including a high specific capacity, extended cycle life and outstanding rate capabilities.