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Review

Carbon nanotube (CNT)-based composites as electrode material for rechargeable Li-ion batteries: A review

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ABSTRACT

The ever-increasing demands for higher energy density and higher power capacity of Li-ion secondary batteries have led to search for electrode materials whose capacities and performance are better than those available today. Carbon nanotubes (CNTs), because of their unique 1D tubular structure, high electrical and thermal conductivities and extremely large surface area, have been considered as ideal additive materials to improve the electrochemical characteristics of both the anode and cathode of Li-ion batteries with much enhanced energy conversion and storage capacities. Recent development of electrode materials for LIBs has been driven mainly by hybrid nanostructures consisting of Li storage compounds and CNTs. In this paper, recent advances are reviewed of the use of CNTs and the methodologies developed to synthesize CNT-based composites for electrode materials. The physical, transport and electrochemical behaviors of the electrodes made from composites containing CNTs are discussed. The electrochemical performance of LIBs affected by the presence of CNTs in terms of energy and power densities, rate capacity, cyclic life and safety are highlighted in comparison with those without or containing other types of carbonaceous materials. The challenges that remain in using CNTs and CNT-based composites, as well as the prospects for exploiting them in the future are discussed.

Contents

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Abbreviations

AB	acetylene black
ACNT	aligned carbon nanotube
C	theoretical capacity
CB	carbon black
CF	carbon fiber
CNT	carbon nanotube
CV	cyclic voltammetry
CVD	chemical vapor deposition
EIS	electrochemical impedance spectra
EVs	electric vehicles
HEVs	hybrid electric vehicles
HRTEM	high resolution transmission electron microscopy
LCO	$LiCoO_2$
ICP	intrinsically conductive polymer
LED	light emitting diode
LFP	$LiFePO_4$
LIB	lithium ion battery
LMO	$LiMn_2O_4$
LNC	$LiNi_{0.7}Co_{0.3}O_2$
NCM	$LiNi_{1/3}Co_{1/3}Mn_{1/3}O_2$
MWCNT	multi-walled carbon nanotube
PANI	polyaniline
PEDOT	poly(3,4-ethylenedioxythiophene)
PVC	poly(N-vinyl carbazole)
PVDF	poly(vinylidene fluoride)
q-CNT	quadrangular carbon nanotube
SEM	scanning electron microscopy
SSB	stationary storage battery
SWCNT	single-walled carbon nanotube
TEM	transmission electron microscopy
UPS	uninterrupted power sources
XRD	X-ray diffraction

1. Introduction

One of the greatest challenges to today's wireless, mobile society is to provide highly-efficient, low cost, and environmentally–friendly energy storage media for powering increasingly diverse applications [1,2]. As the performance of these electronic devices depends largely on the performance of the energy storage media which in turn is affected by the properties of the materials used to synthesize them, significant efforts have been made towards developing new and high-performance materials for battery components. Amongst various energy and power technologies, rechargeable Li-ion batteries (LIB) are a representative of those based on electrochemical energy storage and conversion [3–8]. A typical LIB consists of a negative electrode (i.e. anode, made of graphite), a positive electrode (i.e. cathode, made typically of $LiCoO_2$), and a Li ion conducting electrolyte (see Fig. 1). When the cell is charged, Li ions are extracted from the cathode, move through the electrolyte and are inserted into the anode. Upon discharge, the Li ions are released by the anode and taken up again by the cathode. The electrons pass around the external circuits in opposite directions. The positive electrode half-reaction with charging being forwards is given:

$$LiCoO_2 \leftrightarrows Li_{1-x}CoO_2 + xLi^+ + xe^- \quad (1)$$

while the negative electrode half-reaction is given:

$$xLi^+ + xe^- + 6C \leftrightarrows Li_xC_6 \quad (2)$$

Eqs. (1) and (2) are in units of moles, x is the coefficient typically one for a complete reaction.

Rechargeable LIBs possess many advantages over traditional rechargeable batteries, such as lead acid and Ni–Cd batteries. They include high voltage, high energy-to-weight ratio, i.e. energy density, long cyclic life, no memory effect and slow loss of charge when not in service [1,2]. For these reasons, LIBs are currently the most popular type of battery for powering portable electronic devices and are growing in popularity for defense, automotive and aerospace applications. Although they have shown remarkable commercial successes, the electrodes and their constituent materials are still the subject of intensive research. Diverse range of new applications, such as electric vehicles (EVs), hybrid electric vehicles (HEVs), power tools, uninterrupted power sources (UPS), stationary storage batteries (SSBs), microchips and next-generation wireless communication devices, including 3G mobile phones, are the major driving force behind these research efforts to enhance the ultimate battery performance. In addition to the energy/power density and cyclic performance, safety and cost are two most critical issues that have limited their applications so far in these areas. Because a single type of LIB cannot satisfy all requirements of such a large variety of applications, different types with specific properties and characteristics should be considered. For example, batteries with a high energy capacity are required for high-speed telecommunication devices; whereas batteries with a high power capacity are desirable for EVs, HEVs and power tools.

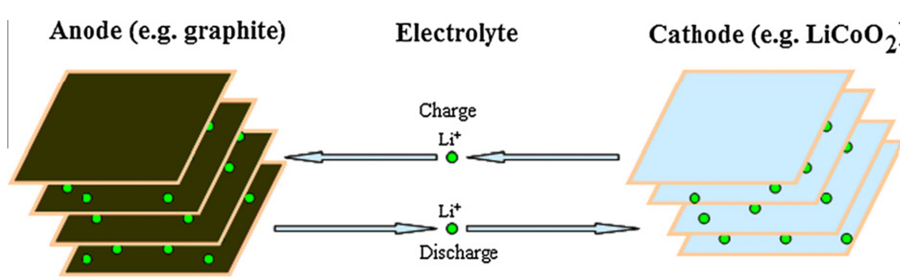

Fig. 1. Working principle of Li-ion batteries. The anode is graphite and cathode is a layered lithiated transition metal oxide. The operation involves a cyclic transfer of Li ions between the electrodes.