



## Review

## Recent developments in cathode materials for lithium ion batteries

Jeffrey W. Fergus\*

Auburn University, Materials Research and Education Center, 275 Wilmore Laboratories, Auburn, AL 36849, United States

## ARTICLE INFO

## Article history:

Received 29 June 2009

Received in revised form 30 August 2009

Accepted 31 August 2009

Available online 6 September 2009

## Keywords:

Lithium ion batteries

Cathodes

Manganese

Nickel

Cobalt

## ABSTRACT

One of the challenges for improving the performance of lithium ion batteries to meet increasingly demanding requirements for energy storage is the development of suitable cathode materials. Cathode materials must be able to accept and release lithium ions repeatedly (for recharging) and quickly (for high current). Transition metal oxides based on the  $\alpha$ - $\text{NaFeO}_2$ , spinel and olivine structures have shown promise, but improvements are needed to reduce cost and extend effective lifetime. In this paper, recent developments in cathode materials for lithium ion batteries are reviewed. This includes comparison of the performance characteristics of the promising cathode materials and approaches for improving their performances.

© 2009 Elsevier B.V. All rights reserved.

## Contents

1. Introduction.....	939
2. Cathode materials.....	940
3. Cathode performance.....	941
4. Composite cathodes.....	943
5. Effect of doping.....	944
6. Effect of microstructure and morphology.....	945
7. Conclusions.....	946
References.....	946

## 1. Introduction

The development of improved battery technology is critical for advancements in a variety of applications ranging from hybrid electric vehicles to consumer electronics [1,2], and improved battery performance depends on the development of materials for the various battery components [3–6]. Most lithium ion batteries use organic solvents as the electrolyte, the most common being  $\text{LiPF}_6$ , which has a low electrical resistance [7], and is typically mixed with carbonates. Solid electrolytes, including polymers [8] and inorganic compounds [9,10], are used for solid state batteries, which have advantages in terms of miniaturization and durability. The most common anode materials are carbon-based compounds and lithium-containing alloys. Both approaches result in the establish-

ment of a reduced lithium activity (as compared to lithium metal), which reduces reactivity with the electrolyte and improves safety, but also leads to a lower cell voltage. There are efforts in the development of improved electrolyte and anode materials, but the focus of this paper is on the cathode materials.

Cathode materials are typically oxides of transition metals, which can undergo oxidation to higher valences when lithium is removed [11,12]. While oxidation of the transition metal can maintain charge neutrality in the compound, large compositional changes often lead to phase changes, so crystal structures that are stable over wide ranges of composition must be used. This structural stability is a particular challenge during charging when most (ideally all) of the lithium is removed from the cathode. During discharge lithium is inserted into the cathode material and electrons from the anode reduce the transition metal ions in the cathode to a lower valence. The rates of these two processes, as well as access of the lithium ions in the electrolyte to the electrode surface, control the maximum discharge current. Exchange of lithium ions with the

\* Tel.: +1 334 844 3405; fax: +1 334 844 3400.

E-mail address: [jwfergus@eng.auburn.edu](mailto:jwfergus@eng.auburn.edu).

electrolyte occurs at the electrode–electrolyte interface, so cathode performance depends critically on the electrode microstructure and morphology, as well as the inherent electrochemical properties of the cathode material. For example, there is considerable work on the use of nanostructured electrodes with high surface and interfacial areas to improve performance [13–17]. While this paper will include some discussion of general microstructural features, the focus is on the cathode materials rather than the microstructures.

## 2. Cathode materials

The cathode material most commonly used in lithium ion batteries is  $\text{LiCoO}_2$  [18].  $\text{LiCoO}_2$  forms the  $\alpha\text{-NaFeO}_2$  structure, which is a distorted rock-salt structure where the cations order in alternating (1 1 1) planes. This ordering results in a trigonal structure ( $R\bar{3}m$ ) and, for  $\text{LiCoO}_2$ , planes of lithium ions through which lithiation and delithiation can occur [19]. Although  $\text{LiCoO}_2$  is a successful cathode material, alternatives are being developed to lower cost and improve stability. Cobalt is less available, and thus more costly, than other transition metals, such as manganese, nickel and iron. In addition,  $\text{LiCoO}_2$  is not as stable as other potential electrode materials and can undergo performance degradation or failure when overcharged [20–22]. The increase in charging voltage can increase the cell capacity, but can also lead to more rapid decrease in capacity as the cell is cycled during recharging [23]. Several reasons have been given for the degradation during cycling. One is that cobalt is dissolved in the electrolyte when the electrode is delithiated during charging [24], such that less lithium can be intercalated during discharge. Another is that the  $\text{CoO}_2$  layer formed after full delithiation shears from the electrode surface [25], which also results in less capacity for lithium intercalation. In addition, there is a sharp change in lattice parameter with change in lithium content [26], which can lead to stresses and micro-cracking of the cathode particles [27]. Stoichiometric  $\text{LiCoO}_2$  can be difficult to obtain [28], so heat treatment to control the surface phase content is needed to improve performance during cycling [29].

$\text{LiNiO}_2$ , which also forms the  $\alpha\text{-NaFeO}_2$  structure, is lower in cost and has a higher energy density (15% higher by volume, 20% higher by weight) [30], but is less stable [31,32] and less ordered [33], as compared to  $\text{LiCoO}_2$ . The lower degree of ordering results in nickel ions occupying sites in the lithium plane, which impedes lithiation/delithiation and also creates challenges in obtaining the appropriate composition [34]. The addition of cobalt to  $\text{LiNiO}_2$  increases the degree of ordering, which leads to nickel ions occupying sites in the nickel/cobalt plane rather than in the lithium plane [12]. Thus,  $\text{LiNi}_{1-x}\text{Co}_x\text{O}_2$ , typically containing mostly nickel ( $x \sim 0.8$ ), has been used to take advantage of the low cost and higher capacity of nickel relative to cobalt [35–39].  $\text{LiMnO}_2$  forms a monoclinic, rather than rhombohedral, structure [40], which can transform to a layered hexagonal structure during cycling [41]. The addition of nickel [42,43], or more commonly nickel and cobalt, to  $\text{LiMnO}_2$  can lead to the formation of the  $\alpha\text{-NaFeO}_2$  structure [44,45]. The ratio of the trigonal lattice parameters,  $c/a$ , depends on the composition, and as this ratio approaches 1.633 the distortion from cubic symmetry decreases, which leads to less ordering and thus more transition metal ions in the lithium ion plane [12]. The most commonly used  $\text{Li}(\text{Ni},\text{Mn},\text{Co})\text{O}_2$  composition contains equal amounts of the three transition metals, *i.e.*  $\text{Li}(\text{Ni}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3})\text{O}_2$ , and has high capacity [46], good rate capability [47,48] and can operate at high voltages. A higher charging voltage increases the capacity, but also leads to more rapid loss of capacity during cycling [49–51]. As with  $\text{LiNi}_{1-x}\text{Co}_x\text{O}_2$ , cobalt helps to reduce the amount of nickel in the lithium layer [12] and small amounts of cobalt (up to 0.20–0.25) have been shown to improve capacity [51–57]. Increased cobalt content can also reduce the loss in capac-

ity during cycling [51,58–60]. The improved performance has been attributed to cobalt increasing the conductivity [51,59] and improving the structural stability [59,60] of the cathode. Although nickel in the lithium layer can be detrimental to lithium transport, it has been shown to stabilize the structure during delithiation and thus improve cycling performance [61].  $\text{Li}(\text{Ni},\text{Mn},\text{Co})\text{O}_2$  can be overlithiated, which has been shown to improve electrode performance [62,63], especially with low cobalt contents [64]. There can be an oxidative loss during the first cycle, which is not recovered during normal cycling [65]. However, deep discharging has been shown to recover this first-cycle loss [66].

Another promising cathode material is  $\text{LiMn}_2\text{O}_4$  that forms a spinel structure ( $Fd\bar{3}m$ ), in which manganese occupies the octahedral sites and lithium predominantly occupies the tetrahedral sites [67]. In this case, the paths for lithiation and delithiation are a 3-dimensional network of channels rather than planes, as in the  $\alpha\text{-NaFeO}_2$  structure.  $\text{LiMn}_2\text{O}_4$ , is lower cost and safer than  $\text{LiCoO}_2$  [12,68,69], but has a lower capacity as compared to the cathode materials that form the  $\alpha\text{-NaFeO}_2$  structure described above [46,70]. One of the challenges in the use of  $\text{LiMn}_2\text{O}_4$  as a cathode material is that phase changes can occur during cycling [71–73]. For example,  $\text{LiMn}_2\text{O}_4$  cathodes have been field tested in the DC power supply of an operating telecommunications transceiver. During this test, a relatively rapid loss of capacity occurred in the first few days, but the rate of capacity loss subsequently decreased [74]. The initial loss has been attributed to loss of oxygen during charging [75]. Capacity loss has also been observed during storage due to dissolution of manganese in the electrolyte [76], or due to changes in particle morphology or crystallinity [77,78]. Other transition metals, including iron [79] and cobalt [80–85], and have been added to  $\text{LiMn}_2\text{O}_4$ . The addition of iron results in an additional discharge plateau at high voltages, while cobalt improves the capacity retention during cycling by stabilizing the spinel crystal structure. However, the most common addition to  $\text{LiMn}_2\text{O}_4$  is nickel [86], which decreases the lattice parameter and the electrical conductivity of  $\text{LiMn}_2\text{O}_4$  [87]. The capacity increases with increasing manganese content and a 3:1 Mn:Ni ratio (*i.e.*  $\text{Mn}_{1.5}\text{Ni}_{0.5}\text{O}_4$ ) is the most commonly used composition [88,89]. The manganese and nickel cations can order on the octahedral sublattice, but a disordered spinel structure has been shown to have a higher capacity [90]. Partial substitution of cobalt for nickel (*i.e.*  $\text{Li}[\text{Mn}_{1.42}\text{Ni}_{0.42}\text{Co}_{0.16}]\text{O}_4$ ) has been used to reduce the formation of  $\text{Li}_x\text{Ni}_{1-x}\text{O}$ , which can degrade cell performance during cycling [91]. The addition of nickel to the surface of  $\text{LiMn}_2\text{O}_4$  through coatings, rather than as a bulk dopant, can also be effective in improving capacity retention during cycling [92–94].

Vanadium oxide forms layered compounds and vanadium can have multiple valences, so vanadium oxides have been used as electrode materials. In particular, orthorhombic  $\text{V}_2\text{O}_5$  [95–99] and monoclinic  $\text{LiV}_3\text{O}_8$  [100–104] have been used as cathode materials. These electrodes have high capacities, but relatively low voltages (typically 3V or less) as compared to the compounds discussed above.

Another promising class of cathode materials are phosphates ( $\text{LiMPO}_4$ ) with the olivine structure ( $Pnma$ ), in which phosphorous occupies tetrahedral sites, the transition metal (M) occupies octahedral sites and lithium forms one-dimensional chains along the [0 1 0] direction [105]. The phosphate most commonly used for the cathode is  $\text{LiFePO}_4$ , which delithiates to  $\text{FePO}_4$  as the  $\text{Fe}^{2+}$  is oxidized to  $\text{Fe}^{3+}$  [106]. Some iron ions occupy lithium sites, which results in the formation of lithium ion vacancies to maintain charge neutrality [107–109]. There is a miscibility gap between  $\text{FePO}_4$  and  $\text{LiFePO}_4$  [110], so the delithiation occurs by growth of a two-phase front rather than a continuous change in lithium content [111–116]. The formation of a two-phase mixture establishes a fixed activity, which results in a relative flat discharge profile (*i.e.* the voltage

remains relatively constant during discharge) [46]. Electronic conduction in  $\text{LiFePO}_4$  occurs by small polaron hopping [117] and is relatively low ( $10^{-9} \text{ S cm}^{-1}$  for pure  $\text{LiFePO}_4$  [12]). Conductivity can be improved by heat treating to increase the hole conductivity [118], but the addition of a conductive phase is generally needed for satisfactory performance [13]. Additives for increasing the conductivity of  $\text{LiFePO}_4$  will be discussed below, but one conductive phase,  $\text{Fe}_2\text{P}$ , can form during preparation and/or use and has been observed to improve performance [119,120], so  $\text{Fe}_2\text{P}$  is sometimes deliberately added in  $\text{LiFePO}_4/\text{Fe}_2\text{P}$  composites [121–124]. The amount of  $\text{Fe}_2\text{P}$  is critical because small amounts increase conductivity, but larger amounts block lithium ion paths [125].

Other phosphates used for cathodes in lithium ion batteries include  $\text{LiMnPO}_4$  [126–128] and  $\text{LiCoPO}_4$  [128,129].  $\text{LiMnPO}_4$  and  $\text{LiCoPO}_4$  have higher open circuit voltages (4.1 and 4.8 V, respectively) than  $\text{LiFePO}_4$  (3.5 V) [12], but have lower capacities. For example, the capacities of  $\text{LiMnPO}_4$  and  $\text{LiCoPO}_4$  prepared by microwave hydrothermal synthesis were reported to be  $\sim 1/6$  and  $\sim 1/3$ , respectively, that of  $\text{LiFePO}_4$  prepared by the same process [128]. In addition,  $\text{Mn}_2\text{P}_4\text{O}_7$  and  $\text{Co}_2\text{P}_4\text{O}_7$  have been observed to form in delithiated  $\text{LiMnPO}_4$  [127] and  $\text{LiCoPO}_4$  [129] electrodes, respectively, which degrades the lifetime and can be a safety concern as oxygen is evolved during the decomposition reaction. Mixtures of phosphates, including  $\text{LiMnPO}_4$  [130–132] or  $\text{LiCoPO}_4$  [133,134] with  $\text{LiFePO}_4$ , have been used for cathode materials. In such mixtures, the operating voltage increases with increasing manganese content [135,136], while capacity increases with increasing iron content [133,134,137]. Although  $\text{LiNiPO}_4$  also forms the olivine structure [105] it is not typically used as a cathode material. However, nickel has been added to other phosphate cathode materials, including simple lithium transition metal phosphates (e.g.  $\text{LiFePO}_4$  [138,139] and  $\text{LiMnPO}_4$  [140]), and complex compounds, (e.g.  $\text{Li}(\text{Mn,Fe})\text{PO}_4$  [141,142] and  $\text{Li}(\text{Mn,Fe,Co})\text{PO}_4$  [143,144]). Another phosphate used as a cathode is  $\text{Li}_3\text{V}_2(\text{PO}_4)_3$ , which forms a monoclinic structure ( $P2_1/n$ ) [145,146].  $\text{Li}_3\text{V}_2(\text{PO}_4)_3$  has a high operating voltage and good performance at high discharge currents [147,148]. For example, plateau voltages of greater than 4 V for discharge currents of 0.2–2C and greater than 3.9 V for a discharge current of 10C have been reported [148]. Vanadium additions have also been shown to improve the capacity of  $\text{LiFePO}_4$ , especially at high discharge currents [138,149,150]. For example, at 0.1C, the increases in capacity are relatively modest (5–15%) [138,149,150], while at 10C increases in capacity of 80% to more than 200% have been observed [149,150]. The beneficial effect of vanadium additions has been attributed to enhancing lithium diffusion [138,150] or reducing the energy required for nucleation of  $\text{LiFePO}_4$  in the  $\text{LiFePO}_4$ - $\text{FePO}_4$  [149] two-phase region.

### 3. Cathode performance

The multitude of materials, geometries and operational variables in lithium ion batteries complicates comparison of the performances of different cathode materials. Although there are a few reports in which different types of electrodes are tested in the same conditions and compared on a single plot (e.g. [47]) most reports focus on a particular type of electrode material with variations in composition or microstructure. On the other hand, summaries of results from different sources (e.g. [151]) may include results for different operating conditions, which complicates making comparisons between materials. The voltage ranges for different electrodes have been summarized [152], but this summary does not include capacities.

In this paper, the performances of different cathodes will be summarized according to operating conditions, so that comparisons can be made between results from different sources. Results

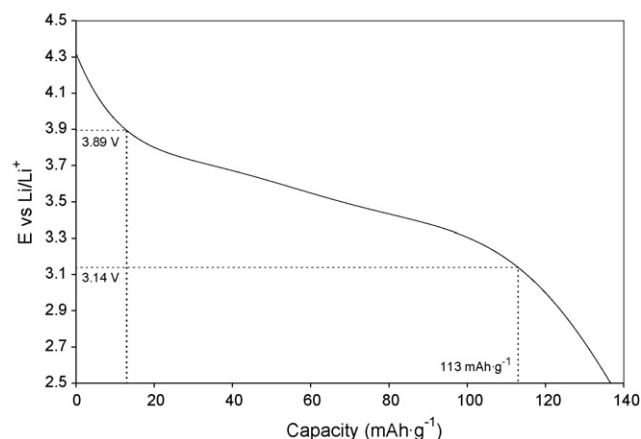


Fig. 1. Schematic discharge curve for lithium ion battery with parameters used in Figs. 2–5.

for different electrodes will be included on the same plots or on different plots with the same scales to allow for direct comparison between materials. In addition, multiple results for each electrode will be included to reflect the variations between reports, which can occur due to, for example, microstructural or morphological differences. To make such comparisons, the voltage range and capacity for each electrode have been determined as shown in Fig. 1. The voltage range is determined by the points of inflection in the discharge curve and the capacity is the capacity at second point of inflection. The capacities determined in this way (Figs. 2–5) are lower than the corresponding maximum capacities, but this method eliminates the lower cut-off voltage as a variable and allows for comparison of results from different sources. The purpose is not to present the absolute maximum capacity, but rather to provide a comparison of the useful voltage/capacity ranges of the voltage plateau for operation. The subsequent plots (Figs. 6–12), however, showing the trends in capacity with discharge current and after cycling use the maximum capacities reported in the respective articles.

The operating voltages and capacities of  $\text{LiFePO}_4$  [123,153–162] and  $\text{LiCoO}_2$  [163–167] with a charging voltage of 4.2 V and discharge current of 1C are shown in Fig. 2. The operating voltage for  $\text{LiCoO}_2$  is higher than that for  $\text{LiFePO}_4$  and  $\text{LiFePO}_4$  has a narrower voltage range. The narrow voltage range for  $\text{LiFePO}_4$  is a result of the formation of a two-phase mixture, rather than a continuous change in lithium content. Fig. 3 shows that a reduction in the discharge current by a factor of 10 (i.e. 0.1C) increases

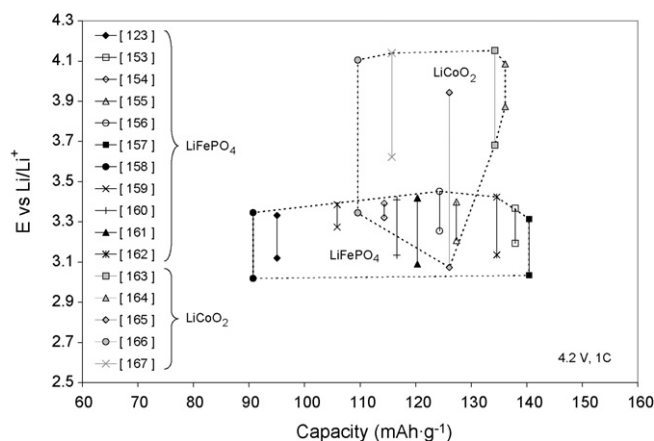


Fig. 2. Plateau voltage and capacity (see Fig. 1) for  $\text{LiFePO}_4$  [123,153–162] and  $\text{LiCoO}_2$  [163–167] with a charging voltage of 4.2 V and discharge current of 1C.

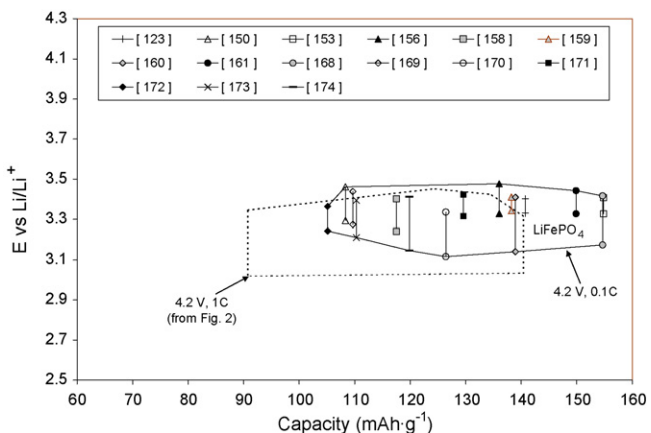


Fig. 3. Plateau voltage and capacity (see Fig. 1) for LiFePO<sub>4</sub> [123,150,153,156,158–161,168–174] with a charging voltage of 4.2 V and discharge current of 0.1C.

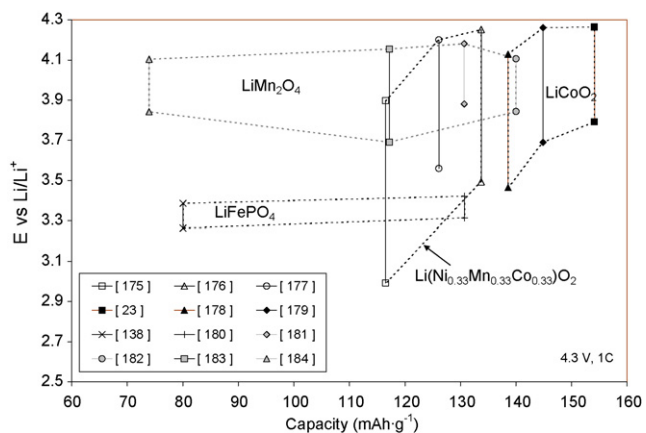


Fig. 4. Plateau voltage and capacity (see Fig. 1) for Li(Ni<sub>1/3</sub>Mn<sub>1/3</sub>Co<sub>1/3</sub>)O<sub>2</sub> [175–177], LiCoO<sub>2</sub> [23,178,179], LiFePO<sub>4</sub> [138,180] and LiMn<sub>2</sub>O<sub>4</sub> [181–184] with a charging voltage of 4.3 V and discharge current of 1C.

the capacity of LiFePO<sub>4</sub> [123,150,153,156,158–161,168–174]. Figs. 4 and 5 summarize the operating voltages and capacities for Li(Ni<sub>1/3</sub>Mn<sub>1/3</sub>Co<sub>1/3</sub>)O<sub>2</sub> [63,175–177], LiCoO<sub>2</sub> [23,178,179,189], LiFePO<sub>4</sub> [138,180] and LiMn<sub>2</sub>O<sub>4</sub> [181–188] at a higher charging voltage of 4.3 V. LiMn<sub>2</sub>O<sub>4</sub>, LiCoO<sub>2</sub> and Li(Ni<sub>1/3</sub>Mn<sub>1/3</sub>Co<sub>1/3</sub>)O<sub>2</sub> all

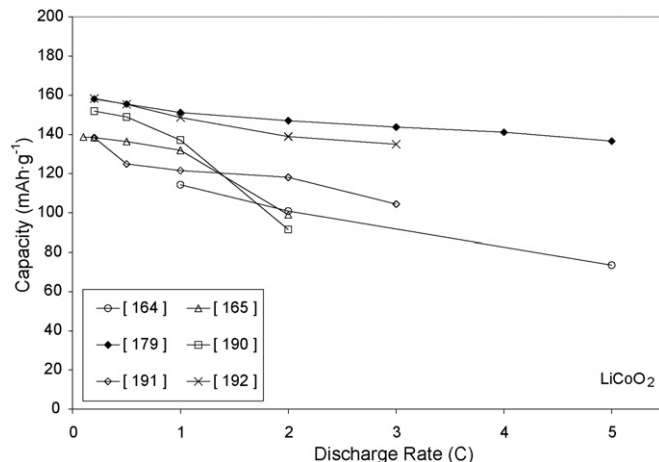


Fig. 6. Discharge capacity of LiCoO<sub>2</sub> as a function of discharge rate [164,165,179,190–192].

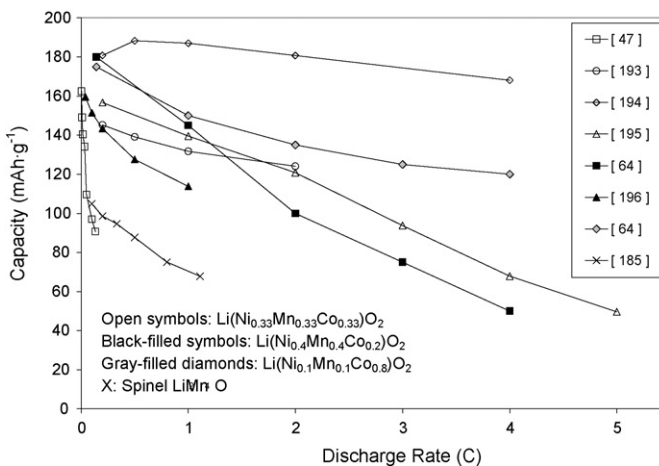


Fig. 7. Discharge capacity of Li(Ni,Mn,Co)O<sub>2</sub> [47,64,193–196] and LiMn<sub>2</sub>O<sub>4</sub> [185] as a function of discharge rate.

have higher operating voltages as compared to LiFePO<sub>4</sub>. LiMn<sub>2</sub>O<sub>4</sub> has a similar, or higher, operating voltage as compared to LiCoO<sub>2</sub> and Li(Ni<sub>1/3</sub>Mn<sub>1/3</sub>Co<sub>1/3</sub>)O<sub>2</sub>, but its capacity is lower. Although the number of data points is small, with a decrease in discharge current from 1 to 0.1C (compare Figs. 4 and 5), the capacity of

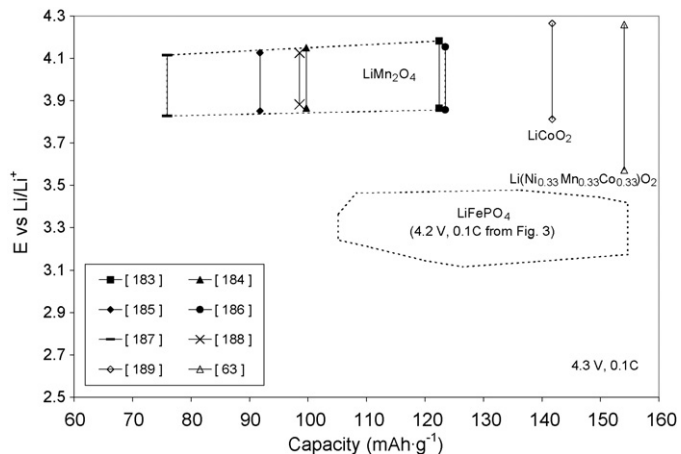


Fig. 5. Plateau voltage and capacity (see Fig. 1) for Li(Ni<sub>1/3</sub>Mn<sub>1/3</sub>Co<sub>1/3</sub>)O<sub>2</sub> [63], LiMn<sub>2</sub>O<sub>4</sub> [183–188] and LiCoO<sub>2</sub> [189] with a charging voltage of 4.3 V and discharge current of 0.1C.

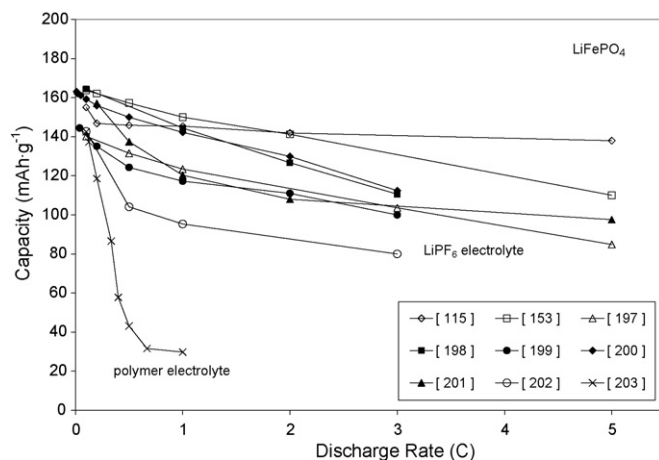


Fig. 8. Discharge capacity of LiFePO<sub>4</sub> as a function of discharge rate [115,153,197–203].



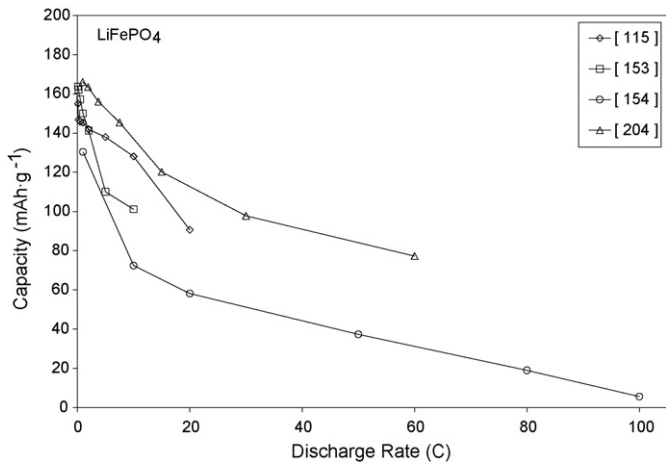


Fig. 9. Discharge capacity of LiFePO<sub>4</sub> at high discharge currents [115,153,154,204].

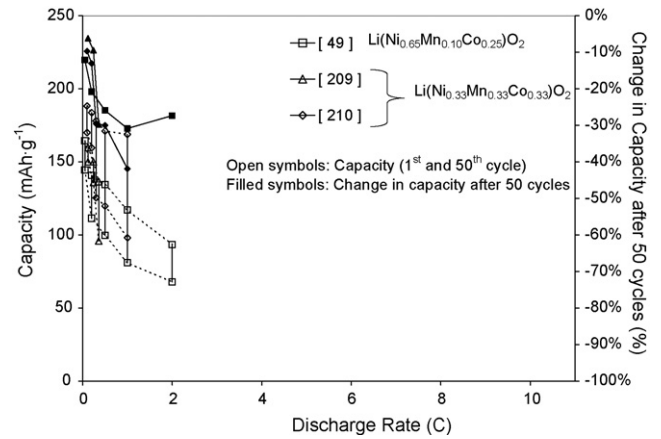


Fig. 12. Capacity after 1st/50th cycle and percent change in capacity after 50 cycles for Li(Ni,Mn,Co)O<sub>2</sub> cathodes [49,209,210].

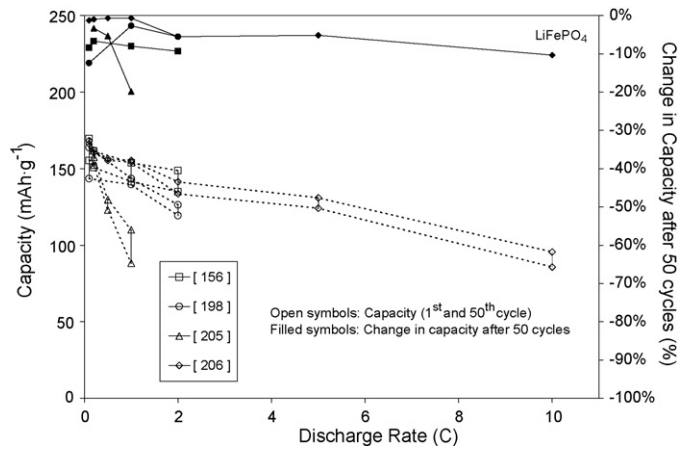


Fig. 10. Capacity after 1st/50th cycle and percent change in capacity after 50 cycles for LiFePO<sub>4</sub> cathodes [156,198,205,206].

Li(Ni<sub>1/3</sub>Mn<sub>1/3</sub>Co<sub>1/3</sub>)O<sub>2</sub> increases more than that of LiCoO<sub>2</sub>, suggesting that the kinetics of charge transfer and/or mass transport are slower in Li(Ni<sub>1/3</sub>Mn<sub>1/3</sub>Co<sub>1/3</sub>)O<sub>2</sub> than in LiCoO<sub>2</sub>.

The trend with discharge current is also illustrated in Figs. 6 and 7, which show the capacity as a function of discharge current for LiCoO<sub>2</sub> [164,165,179,190–192], Li(Ni,Mn,Co)O<sub>2</sub> [47,64,193–196] and LiMn<sub>2</sub>O<sub>4</sub> [185]. Although there is significant variation among the results, the decrease in capacity with increas-

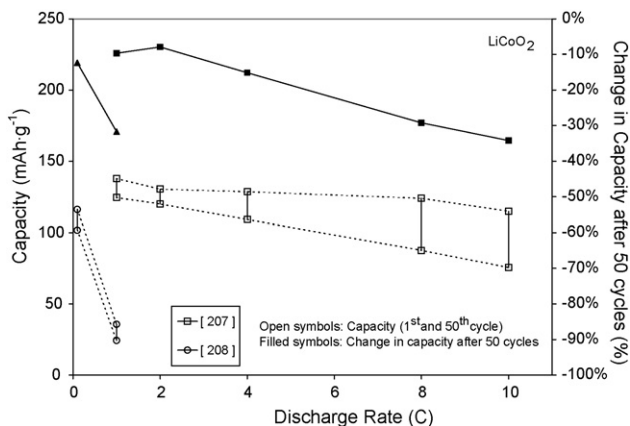


Fig. 11. Capacity after 1st/50th cycle and percent change in capacity after 50 cycles for LiCoO<sub>2</sub> cathodes [207,208].

ing discharge current is generally smaller for LiCoO<sub>2</sub> than for Li(Ni,Mn,Co)O<sub>2</sub>. Fig. 8 shows that the discharge rate dependence of capacity for LiFePO<sub>4</sub> is similar to that for LiCoO<sub>2</sub>. The result exhibiting a rapid decrease in capacity (symbol “x” in Fig. 8) is for a cell with a polymer electrolyte, rather than a liquid LiPF<sub>6</sub>-based electrolyte, so the high current performance may be limited by the electrolyte rather than the electrode. Fig. 9 shows that LiFePO<sub>4</sub> can be used at high discharge currents.

The change in performance during cycling for LiFePO<sub>4</sub> [156,198,205,206], LiCoO<sub>2</sub> [207,208], Li(Ni,Mn,Co)O<sub>2</sub> [49,209,210] are compared in Figs. 10–12 by plotting the capacities after the 1st and 50th cycles as a function of discharge current. In addition, the right axis is used to show the percent change in capacity during the 50 cycles. The decrease in capacity of LiFePO<sub>4</sub> (~10–20%) after cycling is much smaller than that for LiCoO<sub>2</sub> or Li(Ni,Mn,Co)O<sub>2</sub> (~30–40%). These data also illustrate the sharper decrease in capacity with increasing discharge rate for Li(Ni,Mn,Co)O<sub>2</sub> as discussed above.

#### 4. Composite cathodes

The combination of two electrode materials to form a composite electrode can be used to improve performance [211]. For example, the addition of LiFePO<sub>4</sub> to other electrodes, including LiCoO<sub>2</sub> [178,212], Li(Li<sub>0.17</sub>Mn<sub>0.58</sub>Ni<sub>0.25</sub>)O<sub>2</sub> [212] and Li(Ni<sub>0.5</sub>Mn<sub>0.3</sub>Co<sub>0.2</sub>)O<sub>2</sub> [213], improves capacity retention during cycling and performance at high discharge currents. Similarly, a phosphate surface treatment can improve capacity [214] or performance after cycling [215] of oxide electrodes. Monoclinic (C2/m) Li<sub>2</sub>MnO<sub>3</sub> acts as a lithium reserve and improves capacity retention during cycling of layered LiMO<sub>2</sub> cathode materials, including Li(Co<sub>1-y</sub>Ni<sub>y</sub>)O<sub>2</sub> [216], Ni<sub>0.8</sub>Co<sub>0.15</sub>Zr<sub>0.05</sub>O<sub>2</sub> [217], LiNi<sub>0.5</sub>Mn<sub>0.5</sub>O<sub>2</sub> [218], Li(Ni<sub>1/3</sub>Mn<sub>1/3</sub>Co<sub>1/3</sub>)O<sub>2</sub> [218–221] and other Li(Ni,Mn,Co)O<sub>2</sub> compositions [218,222–224]. Spinel electrodes have been combined with layered cathode materials, including LiCoO<sub>2</sub> [225] and Li(Ni,Mn,Co)O<sub>2</sub> [226,227] to expand the operating voltage range. The lithium is removed from the spinel at high voltages and then from Li(Ni,Mn,Co)O<sub>2</sub> at lower voltages [226].

The interface between the two components is where charge and mass transfer occur and is thus important in the operation of the electrode, so mechanical activation [225] or heat treatment [227] has been used to take full advantage of composite properties. LiCoO<sub>2</sub> and Li(Ni,Mn,Co)O<sub>2</sub> have been combined in a composite electrode [228], in which case the improved performance was attributed to the microstructure (*i.e.* combination of large and small particles) rather than to the inherent electrochemical properties of

the cathode materials. This illustrates one of the challenges in comparing electrode materials, in that the performance of the cathode, particular in a two-phase material, depends on the morphology and geometry of its constituents.

Composite cathodes can also be formed by coating particles of one cathode material with another active material rather than mixing separate particles. For example, the cycling and rate capability of  $\text{LiMn}_2\text{O}_4$  has been improved with a  $\text{Co}_3\text{O}_4$  coating, which is purported to form a fluoride layer and reduce electrode degradation [229]. Another example is the reduction in the capacity loss during cycling of  $\text{LiNiO}_2$  with a cobalt–manganese coating, which has been attributed to suppression of a detrimental phase transition [230]. Vanadium compounds, including  $\text{V}_2\text{O}_5$  [231] and  $\text{LiV}_3\text{O}_8$  [223], which have high capacities, but relatively low operating voltages, have been used to increase the capacity of  $\text{Li}(\text{Ni},\text{Mn},\text{Co})\text{O}_2$  by providing supplemental capacity at lower voltages late in the discharge cycle. Another lower voltage electrode that has been used in composite cathodes is  $\text{Li}_4\text{Ti}_5\text{O}_{12}$ . Because of its low voltage ( $\sim 1.5$  V vs.  $\text{Li}/\text{Li}^+$ ),  $\text{Li}_4\text{Ti}_5\text{O}_{12}$  is more commonly used as an anode material, but it can be used as the cathode in low voltage cells [232–236].  $\text{Li}_4\text{Ti}_5\text{O}_{12}$  coatings have been shown to improve the capacity of  $\text{LiCoO}_2$  [237] and  $\text{LiMn}_2\text{O}_4$  [238] cathodes, as well as to improve the capacity retention during cycling of  $\text{LiMn}_{1.4}\text{Cr}_{0.2}\text{Ni}_{0.4}\text{O}_4$  [239]. Similarly, coating  $\text{LiCoO}_2$  with a lithium-conducting solid electrolyte material (LiPON) has also been used to improve the capacity and cycling performance of the cell [240] presumably by enhancing the kinetics and mass transfer at the electrode interface.

## 5. Effect of doping

The performance of cathode materials can be improved by doping, but the interpretation of doping effects can be complicated by the interrelations between doping and microstructure and morphology, since the microstructure formed can be affected by the dopant additions. Some examples in which the effects of doping on the electrochemical properties of the electrode are attributed to the effects of the dopant on the cathode microstructure or morphology rather than the effects on the material properties include cesium-doping of  $\text{LiMn}_2\text{O}_4$  [241], copper-doping of phosphates [140,242] and aluminum-doping of  $\text{LiCoO}_2$  [189]. With that caveat, the effects of dopant additions on the performance of cathode materials are discussed below.

Although iron-based oxides are not typically used as cathode materials, iron is used as a dopant in nickel-, manganese-, and cobalt-based cathode materials. Iron has been shown to improve the capacity of  $\text{LiNiO}_2$  [243,244] and  $\text{Li}_2\text{MnO}_3$  [245,246], but the beneficial effect diminishes with cycling. Iron doping has also been shown to be beneficial to the performance of  $\text{LiNi}_{0.125}\text{Mn}_{0.75}\text{Co}_{0.125}\text{O}_2$  [247], but detrimental to the performance of  $\text{LiNi}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3}\text{O}_2$  [248]. Similarly, iron impurities have been shown to decrease the capacity and increase the capacity loss during cycling of  $\text{LiCoO}_2$  [249]. However, the detrimental effect was attributed to clusters of iron ions, which could be eliminated by annealing the material to disperse the clusters.

Another transition metal that has been used as a dopant for cathode materials is ruthenium, which has been added as a dopant to spinel electrode materials (e.g.  $\text{LiMn}_2\text{O}_4$  [188] and  $\text{LiMn}_{1.5}\text{Ni}_{0.5}\text{O}_4$  [250]) and to  $\text{LiFePO}_4$  [251]. The beneficial effect has been attributed to stabilizing the crystal structure as well as to contributions from the  $\text{Ru}^{4+}/\text{Ru}^{5+}$  redox couple. Ruthenium has also been added as  $\text{RuO}_2$  to  $\text{Li}_3\text{V}_2(\text{PO}_4)_3$  [252] and improved performance by increasing the electrical conductivity.

Chromium forms compounds with the spinel structure and has been added to  $\text{LiMn}_2\text{O}_4$  [54,83] and  $\text{LiMn}_{1.5}\text{Ni}_{0.5}\text{O}_4$  [239,247,253–255]. Chromium reduces the ordering of lithium ions

in  $\text{LiMn}_2\text{O}_4$ , which stabilizes the single phase spinel structure [256], and has been shown to increase the capacity retention during cycling for spinel electrode materials, including  $\text{LiMn}_2\text{O}_4$  [54,83] and  $\text{LiMn}_{1.5}\text{Ni}_{0.5}\text{O}_4$  [254,255]. Nuclear Magnetic Resonance (NMR) analysis indicates the oxidation of  $\text{Mn}^{3+}$  to  $\text{Mn}^{4+}$ , and thus the associated lithium deintercalation, is not uniform, but rather occurs preferentially near the chromium dopant ions [257]. Small amounts of chromium additions have also been shown to improve the performance of other cathode materials including  $\text{Li}[\text{Mn}_{0.5}\text{Ni}_{0.5}]\text{O}_2$  [258,259],  $\text{Li}(\text{Ni}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3})\text{O}_2$  [260],  $\text{V}_2\text{O}_5$  [261] and  $\text{Li}_3\text{V}_2(\text{PO}_4)_3$  [262].

Zinc-doping has been shown to improve the performance of  $\text{Li}[\text{Mn}_{0.4}\text{Mn}_{0.3}\text{Co}_{0.3}]\text{O}_2$  [263],  $\text{LiFePO}_4$  [264], and, through addition of zinc to the electrolyte,  $\text{LiMn}_2\text{O}_4$  [265] by stabilizing the respective crystal structures. However, the beneficial effect of zinc is usually when added in a coating of  $\text{ZnO}$  (e.g.  $\text{LiNi}_{0.5}\text{Mn}_{0.25}\text{Co}_{0.25}\text{O}_2$  [266],  $\text{Li}[\text{Ni}_{0.42}\text{Mn}_{1.42}\text{Co}_{0.16}]\text{O}_4$  [91],  $\text{LiMn}_{1.5}\text{Ni}_{0.5}\text{O}_4$  [267,268],  $\text{LiFePO}_4$  [269]),  $\text{ZnMn}_2\text{O}_4$  (e.g.  $\text{LiMn}_2\text{O}_4$  [270]) or  $\text{Zn}_3(\text{PO}_4)_2$  (e.g.  $\text{LiCoO}_2$  [271]) where it reduces reaction between the electrode and electrolyte.

Titanium is added as a dopant in layered structures ( $\text{Li}(\text{Ni}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3})\text{O}_2$  [248],  $\text{LiNi}_{0.8}\text{Co}_{0.2}\text{O}_2$  [272],  $\text{LiNiO}_2$  [273]), spinels ( $\text{LiMn}_2\text{O}_4$  [274–276],  $\text{LiNi}_{0.5}\text{Mn}_{1.5}\text{O}_4$  [277]) and phosphates ( $\text{LiFePO}_4$  [278],  $\text{LiMnPO}_4$  [126]). Although not beneficial for  $\text{LiNiO}_2$  [273], titanium is beneficial when co-doped with cobalt (i.e.  $\text{LiNi}_{0.8}\text{Co}_{0.2-x}\text{Ti}_x\text{O}_2$ ) [272]. The improved performance is attributed to titanium stabilizing the crystal structure (e.g.  $\text{LiNi}_{0.8}\text{Co}_{0.2}\text{O}_2$  [272],  $\text{Li}(\text{Ni}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3})\text{O}_2$  [248]) or reducing dissolution of the electrode [274–276]. Titanium from impurities in the precursor has been shown to occupy iron sites in  $\text{LiFePO}_4$  and improve electrode performance [279]. Titanium is also added as a  $\text{TiO}_2$  coating to reduce electrode dissolution in the electrolyte [195,280], but degradation of the  $\text{TiO}_2$  can lead to degradation in cell performance [180].

Zirconium has similar effects on cathode performance as titanium. Zirconium doping has been used to stabilize the layered crystal structure (e.g.  $\text{LiCoO}_2$  [23] and  $\text{LiNi}_{0.8}\text{Co}_{0.2}\text{O}_2$  [281]) or in  $\text{LiFePO}_4$  [282–284] to increase the lattice parameter. Zirconium has also been added as a  $\text{ZrO}_2$  or  $\text{Zr}(\text{OBU})_4$  coating to reduce reaction of the electrolyte with cathode materials with layered (e.g.  $\text{LiNi}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3}\text{O}_2$  [177,210] and  $\text{Li}[\text{Li}_{1/6}\text{Ni}_{1/6}\text{Mn}_{1/2}\text{Co}_{1/6}]\text{O}_2$  [285]) and spinel ( $\text{LiMn}_2\text{O}_4$  [183,286] and  $\text{LiMn}_{1.5}\text{Ni}_{0.5}\text{O}_4$  [287]) structures.

Aluminum is a very commonly used dopant in cathode materials. In some cases small amounts of aluminum doping improve the capacity of electrode materials (e.g.  $\text{LiCoO}_2$  [189,288],  $\text{LiNi}_{0.5}\text{Mn}_{0.5}\text{O}_2$  [289–291] and  $\text{LiFePO}_4$  [138]), but in most cases the capacity is decreased (e.g.  $\text{LiCoO}_2$  [189,288],  $\text{LiNi}_{0.5}\text{Mn}_{0.5}\text{O}_2$  [289,292],  $\text{Li}(\text{Ni}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3})\text{O}_2$  [248,260,293–295], other  $\text{Li}(\text{Ni},\text{Mn},\text{Co})\text{O}_2$  compositions [295–297],  $\text{LiMn}_2\text{O}_4$  [83,291,298]). The decreased capacity is expected since  $\text{Al}^{3+}$  cannot be further oxidized, so each transition metal ion replaced with aluminum represents one less oxidizable ion. The observed increases have been attributed to improved electrode kinetics, structural modifications and microstructural effects. For example, the addition of aluminum to  $\text{LiCoO}_2$  results in an increase in lattice parameter  $c$  [288,299], which facilitates lithiation and delithiation. Aluminum doping has also led to improvements in retention of capacity during cycling (e.g.  $\text{Li}(\text{Ni},\text{Mn},\text{Co})\text{O}_2$  [294,297],  $\text{LiMn}_2\text{O}_4$  [83,298]), and performance at high discharge currents (e.g.  $\text{Li}(\text{Ni},\text{Mn},\text{Co})\text{O}_2$  [248,296],  $\text{LiMn}_2\text{O}_4$  [291]). However, there are also cases where cycling performance is degraded with aluminum additions (e.g.  $\text{LiCoO}_2$  [23],  $\text{LiNiO}_2$  [273],  $\text{Li}(\text{Ni}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3})\text{O}_2$  [260,293]). Aluminum is commonly used as a co-dopant with cobalt in  $\text{LiNiO}_2$  (i.e.  $\text{LiNi}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}\text{O}_2$ ) for improved stability [211,300–303]. Aluminum can also be added as an alumina coating and has been

shown to improve the capacity (e.g.  $\text{LiCoO}_2$  [304],  $\text{Li}(\text{Ni},\text{Mn},\text{Co})\text{O}_2$  [52,91],  $\text{LiMn}_{1.5}\text{Ni}_{0.42}\text{Zn}_{0.08}\text{O}_4$  [267],  $\text{LiMn}_2\text{O}_4$  [184]), capacity retention during cycling (e.g.  $\text{LiCoO}_2$  [304,305],  $\text{LiNi}_{0.8}\text{Co}_{0.2}\text{O}_2$  [306],  $\text{Li}(\text{Mn},\text{Ni},\text{Co})\text{O}_2$  [91,286,307],  $\text{LiMn}_{1.5}\text{Ni}_{0.42}\text{Zn}_{0.08}\text{O}_4$  [267],  $\text{LiMn}_2\text{O}_4$  [286]) and performance at high discharge currents [91,267]. The improvements are attributed to improved charge transfer kinetics and improved stability with the electrolyte. Beneficial effects have also been attributed to an  $\text{Al}(\text{OH})_3$  layer, which has led to its use as a coating for  $\text{LiCoO}_2$  [308]. Mixed aluminum oxides, including aluminum-cobalt oxide [309],  $\text{Y}_3\text{Al}_5\text{O}_{12}$  (YAG) [310] and  $\text{La}_3\text{Al}_5\text{O}_{12}$  (LAG) [311], have also been used to improve retention of capacity during cycling. Other forms of aluminum that have been shown to improve electrode performance and stability include  $\text{AlF}_3$  [312–315],  $\text{AlPO}_4$  [91,316–318] and  $(\text{NH}_4)_3\text{AlF}_6$  [319].

Magnesium doping generally improves the performance of phosphate electrodes, including  $\text{LiFePO}_4$  [138,174,320,321] and  $\text{LiMnPO}_4$  [126,140]. The beneficial effect is generally attributed to magnesium increasing the lattice parameter, which facilitates delithiation and stabilizes the structure. Magnesium doping has been reported to improve oxide electrodes by modifying the microstructure (e.g.  $\text{LiCoO}_2$  [322]), or reducing charge transfer resistance (e.g.  $\text{LiNi}_{0.8}\text{Co}_{0.2}\text{O}_2$  [323]), but more often has little, or even a detrimental, effect on electrode performance (e.g.  $\text{LiCoO}_2$  [23,271],  $\text{LiNi}_{0.8}\text{Co}_{0.2}\text{O}_2$  [324],  $\text{Li}(\text{Ni}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3})\text{O}_2$  [260]). However, when present in  $\text{MgO}$  [325] or  $\text{Mg}_3(\text{PO}_4)_2$  [271] coatings, magnesium additions improve electrode performance by reducing the reaction of  $\text{LiCoO}_2$  with the electrolyte. On the other hand, doping with a larger alkaline-earth cation (e.g. calcium [326]) can lead to an increase in lattice parameter of  $\text{LiCoO}_2$  and improved capacity.

Lanthanum additions have been shown to improve the performances of  $\text{LiFePO}_4$  [327,328] and  $\text{LiCoO}_2$  [329] cathodes. One of the benefits of the lanthanum additions is that with  $\text{LiCoO}_2$  a Li-conducting phase ( $\text{La}_2\text{Li}_{0.5}\text{Co}_{0.5}\text{O}_4$ ) is formed, which improves ion transfer across the electrode–electrolyte interface. Such contact resistance is particularly important in solid–solid contacts and oxide additions can also improve contact between cathode particles or between the electrode and electrolyte materials. Some examples include  $\text{CeO}_2$ , which has been shown to reduce contact resistance in  $\text{LiFePO}_4$  cathodes [330], and  $\text{Li}_2\text{SiO}_3$  (and to a lesser extent  $\text{SiO}_2$ ), which has been shown to improve the performance of  $\text{LiCoO}_2$  with a solid electrolyte [331–333].

As mentioned above, some additions improve performance by reducing reaction with the electrolyte. Other oxides added to improve capacity retention by reducing reaction and/or forming a beneficial reaction product with the electrolyte include  $\text{Y}_2\text{O}_3$  [334],  $\text{YPO}_4$  [305],  $\text{B}_2\text{O}_3$  [182],  $\text{SiO}_2$  [335],  $\text{Bi}_2\text{O}_3$  [91,267],  $\text{Sb}_2\text{O}_3$  [336] and  $\text{SnO}_2$  [286]. Some of these same elements when added as a dopant have been reported to improve cycling performance by stabilizing the crystal structure. For example, bismuth has been used as a dopant in  $\text{LiMnO}_2$  [215] and  $\text{LiMn}_2\text{O}_4$  [337], while tin has been used as a dopant in  $\text{LiMn}_2\text{O}_4$  [338]. In such cases there may be multiple benefits as some the oxide may dissolve in the electrode (when an oxide coating is used) or some of the dopant may form a separate phase on the electrode surface (when the cathode is doped). Other dopants that stabilize the crystal structure include rhodium in  $\text{LiCo}_{0.3}\text{Ni}_{0.7}\text{O}_2$  [339], copper in  $\text{LiMnPO}_4$  [140] or  $\text{LiMn}_2\text{O}_4$  [215] and indium in  $\text{LiMnO}_2$  [340]. The effectiveness of indium doping is enhanced by co-doping with sulfur, which occupies the oxygen site [340].

Another dopant that occupies the anion site is fluorine, which is a common element in lithium ion batteries. Fluorine is present in the commonly used  $\text{LiPF}_6$ -based electrolytes [7], as well as in fluorides, such as carbon fluorides, that are used as anodes in lithium ion batteries [315,341]. Although fluoride compounds have been reported as cathode materials (e.g. iron oxyfluoride [342,343]), in cathodes fluorine is more often added to replace oxygen or in a

compound as an additive to oxide cathode materials [315]. For example, fluorine doping has been shown to improve the capacity of spinel cathodes,  $\text{LiMn}_{1.5}\text{Ni}_{0.5}\text{O}_4$  [344] and  $\text{LiMn}_{1.8}\text{Li}_{0.1}\text{Ni}_{0.1}\text{O}_4$  [345], by increasing the lattice parameter and decreasing the average manganese valence. Fluoride additions have also been shown to improve the cycling performance of  $\text{Li}(\text{Ni},\text{Mn},\text{Co})\text{O}_2$ , either as a dopant [346] or a second phase (e.g.  $\text{LiF}$  [347],  $\text{SrF}_2$  [348]) by reducing reaction with the electrolyte.

The electrode reaction involves lithium ions and electrons, so one approach to improving electrode performance is to add a conducting phase to enhance charge transfer. A sputtered gold layer has been used to improve the performance of  $\text{LiFePO}_4$  [349], but this involves an expensive material and process. Silver is lower in cost than gold and has been shown to improve the performance of  $\text{LiCoO}_2$  [207,350],  $\text{LiMn}_2\text{O}_4$  [207] and  $\text{LiNi}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3}\text{O}_2$  [351] cathodes. The beneficial effect of silver is generally attributed to increased conductivity, but increases in lattice parameter have also been reported in  $\text{LiCoO}_2$  [350] and  $\text{LiNi}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3}\text{O}_2$  [351]. Although these metals can improve performance, the most common addition for improving electrode conductivity is carbon.

Carbon is commonly added to cathodes to more effectively utilize the active cathode material, especially at high discharge rates. For example, carbon additions improve the performance of  $\text{LiNi}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3}\text{O}_2$  [175,176,352], spinels ( $\text{LiMn}_2\text{O}_4$  [353] and  $\text{LiMn}_{1.5}\text{Ni}_{0.5}\text{O}_4$  [354]), and especially  $\text{LiFePO}_4$  [161,355–357], which has a relatively low electrical conductivity. The effectiveness of carbon additions depends on the amount and type of carbon used. A thin carbon layer can provide a path for electrons without blocking access for lithium ions [358,359]. There is an optimal amount of carbon, which depends on the microstructure and operating conditions, but is typically on the order of 2–10 wt% [197,198,360–364]. Graphitic carbon generally provides higher conductivity and thus higher rate capacities at large discharge rates, so carbons with large  $\text{sp}^2/\text{sp}^3$  ratios are generally preferred [111,199,202,365]. The particle shape is also important, as nano-scale fibers [158,191,366–370] and high surface area forms of carbon, such as acetylene black [192,371], have been shown to be effective in improving cathode performance. In addition to providing paths for electrical conduction, nano-scale fibers can also be used to disperse the cathode particles for increased contact with the electrolyte [372]. The type and morphology of the carbon deposits depends on the source of the carbon [373], which include glucose [374–376], sucrose [156] and malonic acid [377,378], as well as oligomers [379] and polymers [380,381]. In addition to being used as precursors for carbon, polymers can be used in the electrode. In particular, semiconducting [170,382] or conducting polymers (e.g. polypyrrole (PPy) [162,201,383,384] and polyaniline [385,386]) have been used as additives in cathodes.

## 6. Effect of microstructure and morphology

As mentioned above, electrode performance depends on the electrode microstructure and morphology. Although the focus of this paper is on the materials rather than morphology, some general aspects of electrode morphology will be discussed. Intercalation and deintercalation occur along specific crystallographic planes and directions, so higher crystallinity improves electrode performance (e.g.  $\text{LiCoO}_2$  [387],  $\text{LiMn}_2\text{O}_4$  [388],  $\text{Li}_{1.02}\text{Mn}_{1.5}\text{Ni}_{0.5}\text{O}_4$  [389],  $\text{LiFePO}_4$  [155,390–392]).

The electrode reaction occurs at the surface and requires transport of ions into the electrode material, so small particles, which provide high surface area [388] and short diffusion distances [393], and are generally desired (e.g.  $\text{LiCoO}_2$  [164,394,395],  $\text{LiNi}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3}\text{O}_2$  [396],  $\text{LiMn}_2\text{O}_4$  [181,397,398] and  $\text{LiFePO}_4$  [155,157,171,399–402]). However, particles can become too small,



so that processes other than the surface reaction, such as diffusion of ions in the electrolyte to the particle surface, become rate limiting. In addition, the high reactivity of nanosize particles can be disadvantageous in terms of safety and stability during long operational lifetimes [12,403]. Thus, intermediate particle sizes sometimes exhibit the best performance [404–406]. For example, analysis of the discharge of individual  $\text{LiCoO}_2$  particles suggests that commercially available micron-size particles have sufficient capacity, so nanoparticles may not be necessary [407]. Similarly, micron-scale carbon fibers have been used to provide a framework for dispersion of  $\text{LiFePO}_4$  particles to improve access to lithium ions in the electrolyte [408]. In addition, control of porosity is important to allow for access of the electrolyte to the electrode surface [194,409–412]. For example, a recent report has shown that nanoporous micron-size particles perform better than nanoparticles [413].

Particle shape is important for electrode performance. For  $\text{LiMn}_2\text{O}_4$  spinel electrodes, spherical particles have been reported to provide the best performance [414,415], which may be related to the more isotropic lithium transport in the spinel structure, as compared to layered structures. For layered structures, including  $\text{LiCoO}_2$  [416] and  $\text{LiNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}\text{O}_2$  [417], however, non-spherical particles have been shown to improve performance, which has been attributed to high tap density. Rod- or needle-shaped particles, which have large surface-to-volume ratios, have also shown good performance, especially during cycling and at high discharge currents [418–420]. Rod-shaped particles can also be useful as precursors to produce small nano-scale spherical particles [421]. Plate-like particles, which reflect the layered crystal structure, have also been used [204,422,423], and can better accommodate expansion/contraction during intercalation/deintercalation and reduce cracking. In addition to the overall particle shape, the surface morphology is also important. For example, a “desert rose” surface morphology on  $\text{LiCoO}_2$  produces a high surface area, which results in a high capacity [424].

The production of small power supplies for miniature devices requires thin-film based batteries, so thin-film deposition of cathode materials is required for these applications [425]. Thin-film deposition techniques, such as pulsed laser deposition and sputtering, have been used to produce cathode materials including  $\text{LiCoO}_2$  [426–430],  $\text{LiMn}_2\text{O}_4$  [431–435],  $\text{LiFePO}_4$  [436]. The small batteries have high energy densities, but the energy density can be further improved by using three-dimensional architectures [437,438]. Such three-dimensional geometries require templates for control of the size, shape and arrangement of the battery components [439]. Approaches for producing such complex geometries can be inspired by biological systems [440], and can even use biological processes for fabrication [441–443]. The processes required to fabricate these complex geometries will likely place additional constraints on materials selection, so further developments in cathode materials and fabrication processes will be required.

## 7. Conclusions

The development of improved cathode materials is a challenge for meeting current and future energy storage requirements. Several transition metal based cathode materials can provide high voltages and good capacities. Full utilization of these materials for numerous recharging cycles and at high discharge currents continues to be a challenge. Specifically, stabilizing the desired crystal structure, especially during delithiation, and preventing reaction with the electrolyte are important for long operational life, while improved transport to and in the electrode are important for achieving high discharge current. Progress has been made by

engineering the electrode composition, microstructure and morphology, but additional improvements are needed.

## References

- [1] M. Armand, J.-M. Tarascon, Building better batteries, *Nature* 451 (2008) 652–657.
- [2] C. Daniel, Materials and processing for lithium-ion batteries, *JOM* 60 (9) (2008) 43–48.
- [3] M.S. Whittingham, Materials challenges facing electrical energy storage, *MRS Bull.* 33 (4) (2008) 411–419.
- [4] A. Patil, V. Patil, D.W. Shin, J.-W. Choi, D.-S. Paik, S.-J. Yoon, Issue and challenges facing rechargeable thin film lithium batteries, *Mater. Res. Bull.* 43 (2008) 1913–1942.
- [5] J. Hassoun, P. Reale, B. Scrosati, Recent advances in liquid and polymer lithium-ion batteries, *J. Mater. Chem.* 17 (2007) 3668–3677.
- [6] A.K. Shukla, T.P. Kumar, Materials for next-generation lithium batteries, *Curr. Sci.* 94 (2008) 314–331.
- [7] D.P. Abraham, M.M. Furczon, S.-H. Kang, D.W. Dees, A.N. Jansen, Effect of electrolyte composition on initial cycling and impedance characteristics of lithium-ion cells, *J. Power Sources* 180 (2008) 612–620.
- [8] A.M. Stephan, K.S. Nahm, Review on composite polymer electrolytes for lithium batteries, *Polymer* 47 (2006) 5952–5964.
- [9] P. Knauth, Inorganic solid Li ion conductors: an overview, *Solid State Ionics* 180 (2009) 911–916.
- [10] V. Thangadurai, W. Weppner, Recent progress in solid oxide and lithium ion conducting electrolytes research, *Ionics* 12 (2006) 81–92.
- [11] D. Guyomard, Advanced cathode materials for lithium batteries, in: *Energy Storage Systems for Electronics*, in: T. Osaka, M. Datta (Eds.), *New Trends in Electrochemical Technology*, vol. 1, Gordon and Breach, Amsterdam, 2000, pp. 253–350.
- [12] M.S. Whittingham, Lithium batteries and cathode materials, *Chem. Rev.* 104 (2004) 4271–4301.
- [13] Y. Wang, G. Cao, Developments in nanostructured cathode materials for high-performance lithium-ion batteries, *Adv. Mater.* 20 (2008) 2251–2269.
- [14] C.R. Sides, C.R. Martin, Nanomaterials in Li-ion battery electrode design, in: R.E. White, C.G. Vayenas, M.E. Gamboa-Aldeco (Eds.), *Modern Aspects of Electrochemistry*, vol. 8, Springer, New York, NY, 2007, pp. 75–126.
- [15] E. Antolini,  $\text{LiCoO}_2$ : Formation, structure, lithium and oxygen nonstoichiometry, electrochemical behavior and transport properties, *Solid State Ionics* 170 (2004) 159–171.
- [16] J. Akimoto, Y. Gotoh, Y. Oosawa, Synthesis and structure refinement of  $\text{LiCoO}_2$  single crystals, *J. Solid State Chem.* 141 (1998) 298–302.
- [17] D. Belov, M.-H. Yang, Investigation of the kinetic mechanism in overcharge process for Li-ion battery, *Solid State Ionics* 179 (2008) 1816–1821.
- [18] D. Belov, M.-H. Yang, Failure mechanism of Li-ion battery at overcharge conditions, *J. Solid State Electrochem.* 12 (2008) 885–894.
- [19] C.-H. Doh, D.-H. Kim, H.-S. Kim, H.-M. Shin, Y.-D. Jeong, S.-I. Moon, B.-S. Jin, S.W. Eom, H.-S. Kim, K.-W. Kim, D.-H. Oh, A. Veluchamy, Thermal and electrochemical behaviour of  $\text{C/Li}_x\text{CoO}_2$  cell during safety test, *J. Power Sources* 175 (2008) 881–885.
- [20] Y. Takahashi, S. Tode, A. Kinoshita, H. Fujimoto, I. Nakane, S. Fujitani, Development of lithium-ion batteries with a  $\text{LiCoO}_2$  cathode toward high capacity by elevating charging potential, *J. Electrochem. Soc.* 155 (7) (2008) A537–A541.
- [21] G.G. Amatucci, J.M. Tarascon, L.C. Klein, Cobalt dissolution in  $\text{LiCoO}_2$ -based non-aqueous rechargeable batteries, *Solid State Ionics* 83 (1996) 167–173.
- [22] G.G. Amatucci, J.M. Tarascon, L.C. Klein,  $\text{CoO}_2$ , the end member of the  $\text{Li}_x\text{CoO}_2$  solid solution, *J. Electrochem. Soc.* 143 (3) (1996) 1114–1123.
- [23] T. Ohzuku, A. Ueda, Solid-state redox reaction of  $\text{LiCoO}_2$  (R3m) for 4 volt secondary lithium cells, *J. Electrochem. Soc.* 141 (11) (1994) 2677–2972.
- [24] J. Zhou, P.H.L. Notten, Studies on the degradation of Li-ion batteries by the use of microreference electrodes, *J. Power Sources* 177 (2008) 553–560.
- [25] M. Ménétrier, D. Carlier, M. Blangero, C. Delmas, On “really” stoichiometric  $\text{LiCoO}_2$ , *Electrochem. Solid-State Lett.* 11 (11) (2008) A179–A182.
- [26] N. Pereira, J.F. Al-Sharab, F. Cosandey, F. Badway, G.G. Amatucci, Thermodynamically induced surface modification for the stabilization of high-capacity  $\text{LiCoO}_2$ , *J. Electrochem. Soc.* 155 (11) (2008) A831–A838.
- [27] A. Yamada, S.C. Chung, K. Hinokuma, Optimized  $\text{LiFePO}_4$  for lithium battery cathodes, *J. Electrochem. Soc.* 148 (3) (2001) A224–A229.
- [28] T. Amriou, B. Khelifa, H. Aourag, S.M. Aouadi, C. Mathieu, Ab initio investigation of the Jahn–Teller distortion effect on the stabilizing lithium intercalated compounds, *Mater. Chem. Phys.* 92 (2005) 499–504.
- [29] H. Liu, Y. Yang, J. Zhang, Reaction mechanism and kinetics of lithium ion battery cathode material  $\text{LiNiO}_2$  with  $\text{CO}_2$ , *J. Power Sources* 173 (2007) 556–561.
- [30] A. Rougier, P. Bravereau, D. Delmas, Optimization of the composition of the  $\text{Li}_{1-x}\text{Ni}_{1+x}\text{O}_2$  electrode materials: Structural, magnetic, and electrochemical studies, *J. Electrochem. Soc.* 143 (4) (1996) 1168–1175.
- [31] T. Thongtem, S. Thongtem, Characterization of  $\text{Li}_{1-x}\text{Ni}_{1+x}\text{O}_2$  prepared using succinic acid as a complexing agent, *Inorg. Mater.* 42 (2) (2006) 202–209.



- [35] X. Shi, C. Wang, X. Ma, J. Sun, Synthesis and electrochemical properties of  $\text{LiNi}_{0.9}\text{Co}_{0.1}\text{O}_2$  cathode material for lithium secondary battery, *Mater. Chem. Phys.* 113 (2009) 780–783.
- [36] D.G. Lee, R.K. Gupta, Y.S. Cho, K.T. Hwang, Improved electrochemical properties of  $\text{Li}(\text{Ni}_{0.7}\text{Co}_{0.3})\text{O}_2$  cathode for lithium ion batteries with controlled sintering conditions, *J. Appl. Electrochem.* 39 (2009) 671–679.
- [37] D. Li, Z. Peng, H. Ren, W. Guo, Y. Zhou, Synthesis and characterization of  $\text{LiNi}_{1-x}\text{Co}_x\text{O}_2$  for lithium batteries by a novel method, *Mater. Chem. Phys.* 107 (2008) 171–176.
- [38] R. Baskaran, N. Kuwata, O. Kamishima, J. Kawamura, S. Selvasekarapandian, Structural and electrochemical studies on thin film  $\text{LiNi}_{0.8}\text{Co}_{0.2}\text{O}_2$  by PLD for micro battery, *Solid State Ionics* 180 (2009) 636–643.
- [39] K. Sakamoto, M. Hirayama, N. Sonoyama, D. Mori, A. Yamada, K. Tamura, J. Mizuki, R. Kanno, Surface structure of  $\text{LiNi}_{0.8}\text{Co}_{0.2}\text{O}_2$ : A new experimental technique using in situ x-ray diffraction and two-dimensional epitaxial film electrodes, *Chem. Mater.* 21 (13) (2009) 2632–2640.
- [40] A.R. Armstrong, A.D. Robertson, P.G. Bruce, Structural transformation on cycling layered  $\text{Li}(\text{Mn}_{1-y}\text{Co}_y)\text{O}_2$  cathode materials, *Electrochim. Acta* 45 (1999) 285–294.
- [41] B. Ammundsen, J. Desilvestro, T. Groutso, D. Hassell, J.B. Metson, E. Regan, R. Steiner, P.J. Pickering, Formation and structural properties of layered  $\text{LiMnO}_2$  cathode materials, *J. Electrochem. Soc.* 147 (11) (2000) 4078–4082.
- [42] H.Y. Xu, Q.Y. Wang, C.H. Chen, Synthesis of  $\text{Li}[\text{Li}_{0.2}\text{Ni}_{0.2}\text{Mn}_{0.6}]\text{O}_2$  by radiated polymer gel method and impact of deficient Li on its structure and electrochemical properties, *J. Solid State Electrochem.* 12 (2008) 1173–1178.
- [43] M. Jiang, B. Key, Y.S. Meng, C.P. Grey, Electrochemical and structural study of the layered, “Li-excess” lithium-ion battery electrode material  $\text{Li}[\text{Li}_{1/9}\text{Ni}_{1/3}\text{Mn}_{5/9}]\text{O}_2$ , *Chem. Mater.* 21 (13) (2009) 2733–2745.
- [44] L. Wang, J. Li, X. He, W. Pu, C. Wan, C. Jiang, Recent advances in layered  $\text{LiNi}_x\text{Co}_y\text{Mn}_{1-x-y}\text{O}_2$  cathode materials for lithium ion batteries, *J. Solid State Electrochem.* 13 (2009) 1157–1164.
- [45] Y. Wu, A. Manthiram, Structural stability of chemically delithiated layered  $(1-z)\text{Li}[\text{Li}_{1/3}\text{Mn}_{2/3}]\text{O}_{2-z}-\text{Li}[\text{Mn}_{0.5-y}\text{Ni}_{0.5-y}\text{Co}_{2y}]\text{O}_2$  solid solution cathodes, *J. Power Sources* 183 (2008) 749–754.
- [46] S.G. Stewart, V. Srinivasan, J. Newman, Modeling the performance of lithium-ion batteries and capacitors during hybrid-electric-vehicle operation, *J. Electrochem. Soc.* 155 (9) (2008) A664–A671.
- [47] S.K. Martha, E. Markevich, V. Burgel, G. Salitra, E. Zinigrad, B. Markovsky, H. Sclar, Z. Pramovich, O. Heik, D. Aurbach, I. Exnar, H. Buqa, T. Drezon, G. Semrau, M. Schmidt, D. Kovacheva, N. Saliyski, A short review on surface chemical aspects of Li batteries: A key for a good performance, *J. Power Sources* 189 (2009) 288–296.
- [48] S.K. Martha, H. Sclar, Z.S. Framowitz, D. Kovacheva, N. Saliyski, Y. Gofer, P. Sharon, E. Golik, B. Markovsky, D. Aurbach, A comparative study of electrodes comprising nanometric and submicron particles of  $\text{LiNi}_{0.50}\text{Mn}_{0.50}\text{O}_2$ ,  $\text{LiNi}_{0.33}\text{Mn}_{0.33}\text{Co}_{0.33}\text{O}_2$ , and  $\text{LiNi}_{0.40}\text{Mn}_{0.40}\text{Co}_{0.20}\text{O}_2$  layered compounds, *J. Power Sources* 189 (2009) 248–255.
- [49] M. Dabbi, J.M. Wikberg, I. Saadoun, T. Gustafsson, P. Svedlindh, K. Edström, A delithiated  $\text{LiNi}_{0.65}\text{Co}_{0.25}\text{Mn}_{0.10}\text{O}_2$  electrode material: A structural, magnetic and electrochemical study, *Electrochim. Acta* 54 (2009) 3211–3217.
- [50] C.-H. Lu, Y.-K. Lin, Microemulsion preparation and electrochemical characteristics of  $\text{LiNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}\text{O}_2$  powders, *J. Power Sources* 189 (2009) 40–44.
- [51] D. Li, C. Yuan, J. Dong, Z. Peng, Y. Zhou, Synthesis and electrochemical properties of  $\text{LiNi}_{0.85-x}\text{Co}_x\text{Mn}_{0.15}\text{O}_2$  as cathode materials for lithium-ion batteries, *J. Solid State Electrochem.* 12 (2008) 323–327.
- [52] Y. Wu, A. Manthiram, Effect of surface modifications on the layered solid solution cathodes  $(1-z)\text{Li}[\text{Li}_{1/3}\text{Mn}_{2/3}]\text{O}_{2-z}-\text{Li}[\text{Mn}_{0.5-y}\text{Ni}_{0.5-y}\text{Co}_{2y}]\text{O}_2$ , *Solid State Ionics* 180 (2009) 50–56.
- [53] N.V. Kosova, E.T. Devyatkina, V.V. Kaichev, D.G. Kellerman, Effect of electronic state of ions on the electrochemical properties of layered cathode materials  $\text{LiNi}_{1-2x}\text{Co}_x\text{Mn}_x\text{O}_2$ , *Russ. J. Electrochem.* 44 (5) (2008) 543–549.
- [54] A.V. Churikov, E.I. Kachibaya, V.O. Sycheva, I.A. Ivanishcheva, R.I. Imnadze, T.V. Paikidze, A.V. Ivanishchev, Electrochemical properties of  $\text{LiMn}_{2-y}\text{Me}_y\text{O}_4$  (Me = Cr, Co, Ni) spinels as cathodic materials for lithium-ion batteries, *Russ. J. Electrochem.* 45 (2) (2009) 175–182.
- [55] S.-T. Myung, A. Ogata, K.-S. Lee, S. Komaba, Y.-K. Sun, H. Yashiro, Structural electrochemical, and thermal aspects of  $\text{Li}[(\text{Ni}_{0.5}\text{Mn}_{0.5})_{1-x}\text{Co}_x]\text{O}_2$  ( $0 \leq x \leq 0.2$ ) for high-voltage application of lithium-ion secondary batteries, *J. Electrochem. Soc.* 155 (5) (2008) A374–A383.
- [56] J. Li, L. Wang, Q. Zhang, X.-M. He, Synthesis and characterization of  $\text{LiNi}_{0.6}\text{Mn}_{0.4-x}\text{Co}_x\text{O}_2$  as cathode materials for Li-ion batteries, *J. Power Sources* 189 (2009) 28–33.
- [57] H. Bang, D.-H. Kim, Y.C. Bae, J. Prakash, Y.-K. Sun, Effects of metal ions on the structural and thermal stabilities of  $\text{Li}[\text{Ni}_{1-x-y}\text{Co}_x\text{Mn}_y]\text{O}_2$  ( $x+y \leq 0.5$ ) studied by in situ high temperature XRD, *J. Electrochem. Soc.* 155 (12) (2008) A952–A958.
- [58] J. Xiao, N.A. Chernova, M.S. Whittingham, Layered mixed transition metal oxide cathodes with reduced cobalt content for lithium ion batteries, *Chem. Mater.* 20 (24) (2008) 7454–7464.
- [59] S.W. Oh, S.-T. Myung, H.B. Kang, Y.-K. Sun, Effects of Co doping on  $\text{Li}[\text{Ni}_{0.5}\text{Co}_x\text{Mn}_{1.5-x}]\text{O}_4$  spinel materials for 5 V lithium secondary batteries via co-precipitation, *J. Power Sources* 189 (2009) 752–756.
- [60] H.M. Wu, J.P. Tu, Y.F. Yuan, J.Y. Xiang, X.T. Chen, X.B. Zhao, G.S. Cao, Effects of abundant Co doping on the structure and electrochemical characteristics of  $\text{LiMn}_{1.5}\text{Ni}_{0.5-x}\text{Co}_x\text{O}_4$ , *J. Electroanal. Chem.* 608 (2007) 8–14.
- [61] F. Rosciano, J.-F. Colin, F. La Mantia, N. Tran, P. Novák, Electrochemical stress at high potential to investigate phase transitions in  $\text{Li}_{1.1}(\text{Ni}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3})_{0.9}\text{O}_2$ , *Electrochem. Solid-State Lett.* 12 (7) (2009) A140–A144.
- [62] N. Tran, L. Croguennec, M. Ménétrier, F. Weill, Ph. Biensan, C. Jordy, C. Delmas, Mechanisms associated with the “plateau” observed at high voltage for the overlithiated  $\text{Li}_{1.2}(\text{Ni}_{0.425}\text{Mn}_{0.425}\text{Co}_{0.15})_{0.88}\text{O}_2$  system, *Chem. Mater.* 20 (15) (2008) 4815–4825.
- [63] S.-H. Park, S.-H. Kang, I. Belharouak, Y.K. Sun, K. Amine, Physical and electrochemical properties of spherical  $\text{Li}_{1+x}(\text{Ni}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3})_{1-x}\text{O}_2$  cathode materials, *J. Power Sources* 177 (2008) 177–183.
- [64] J.-M. Kim, N. Kumagai, T.-H. Cho, Synthesis, structure, and electrochemical characteristics of overlithiated  $\text{Li}_{1+x}(\text{Ni}_z\text{Co}_{1-2z}\text{Mn}_z)_{1-x}\text{O}_2$  ( $z=0.1-0.4$  and  $x=0.0-0.1$ ) positive electrodes prepared by spray-drying method, *J. Electrochem. Soc.* 155 (1) (2008) A82–A89.
- [65] F. La Mantia, F. Rosciano, N. Tran, P. Novák, Direct evidence of oxygen evolution from  $\text{Li}_{1+x}(\text{Ni}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3})_{1-x}\text{O}_2$  at high potentials, *J. Appl. Electrochem.* 38 (2008) 893–896.
- [66] S.-H. Kang, D.P. Abraham, W.-S. Yoon, K.-W. Nam, X.-Q. Yang, First-cycle irreversibility of layered Li–Ni–Co–Mn oxide cathode in Li-ion batteries, *Electrochim. Acta* 54 (2008) 684–689.
- [67] M.M. Thackeray, A. de Kock, W.I.F. David, Synthesis and structural characterization of defect spinels in the lithium-manganese-oxide system, *Mater. Res. Bull.* 28 (1993) 1041–1049.
- [68] A.D. Pasquier, C.C. Huang, T. Spitler, Nano  $\text{Li}_4\text{Tl}_5\text{O}_{12}-\text{LiMn}_2\text{O}_4$  batteries with high power capability, improved cycle-life, *J. Power Sources* 186 (2009) 508–514.
- [69] I. Belharouak, Y.-K. Sun, W. Lu, K. Amine, On the safety of the  $\text{Li}_4\text{Tl}_5\text{O}_{12}/\text{LiMn}_2\text{O}_4$  lithium-ion battery system, *J. Electrochem. Soc.* 154 (12) (2007) A1083–A1087.
- [70] N. Takami, H. Inagaki, T. Kishi, Y. Harada, Y. Fujita, K. Hoshina, Electrochemical kinetics and safety of 2-volt class Li-ion battery system using lithium titanium oxide anode, *J. Electrochem. Soc.* 156 (2) (2009) A128–A132.
- [71] Q. Liu, D. Mao, C. Chang, F. Huang, Phase conversion and morphology evolution during hydrothermal preparation of orthorhombic  $\text{LiMnO}_2$  nanorods for lithium ion battery application, *J. Power Sources* 173 (2007) 538–544.
- [72] J. Molenda, M. Ziemnick, J. Marzec, W. Zając, M. Molenda, M. Bućko, Electrochemical and high temperature physicochemical properties of orthorhombic  $\text{LiMnO}_2$ , *J. Power Sources* 173 (2007) 707–711.
- [73] M.M. Thackeray, Spinel electrodes for lithium batteries, *J. Am. Ceram. Soc.* 82 (12) (1999) 3347–3354.
- [74] T. Matsushima, Deterioration estimation of lithium-ion cells in direct current power supply systems and characteristics of 400-Ah lithium-ion cells, *J. Power Sources* 189 (2009) 847–854.
- [75] B. Deng, H. Nakamura, M. Yoshio, Capacity fading with oxygen loss for manganese spinels upon cycling at elevated temperatures, *J. Power Sources* 180 (2008) 864–868.
- [76] Y. Liu, X. Li, H. Guo, Z. Wang, Q. Hu, W. Peng, Y. Yang, Electrochemical performance and capacity fading reason of  $\text{LiMn}_2\text{O}_4/\text{graphite}$  batteries stored at room temperature, *J. Power Sources* 189 (2009) 721–725.
- [77] T. Doi, M. Inaba, H. Tsuchiya, S.-K. Jeong, Y. Iriyama, T. Abe, Z. Ogumi, Electrochemical AFM study of  $\text{LiMn}_2\text{O}_4$  thin film electrodes exposed to elevated temperatures, *J. Power Sources* 180 (2008) 539–545.
- [78] Yu.G. Mateyshina, U. Lafont, N.F. Uvarov, E.M. Kelder, Physical and electrochemical properties of  $\text{LiFe}_{0.5}\text{Mn}_{1.5}\text{O}_4$  spinel synthesized by different methods, *Russ. J. Electrochem.* 45 (5) (2009) 602–605.
- [79] H. Shigemura, H. Sakaebe, H. Kageyama, H. Kobayashi, A.R. West, R. Kanno, S. Morimoto, S. Nasu, M. Tabuchi, Structure and electrochemical properties of  $\text{LiFe}_x\text{Mn}_{2-x}\text{O}_4$  ( $0 \leq x \leq 0.5$ ) spinel as 5 V electrode material for lithium batteries, *J. Electrochem. Soc.* 148 (7) (2001) A736–A760.
- [80] P. Arora, B.N. Popov, R.E. White, Electrochemical investigations of cobalt-doped  $\text{LiMn}_2\text{O}_4$  as cathode material for lithium-ion batteries, *J. Electrochem. Soc.* 145 (3) (1998) 807–815.
- [81] C. Wang, S. Lu, S. Kan, J. Pang, W. Jin, X. Zhang, Enhanced capacity retention of Co and Li doubly doped  $\text{LiMn}_2\text{O}_4$ , *J. Power Sources* 189 (2009) 607–610.
- [82] N. Amdouni, F. Gendron, A. Mauger, C.M. Julien, Structural, magnetic and electrochemical properties of the spinel  $\text{LiMn}_{2-y}\text{Co}_y\text{O}_4$  nanosized powders, *Mater. Res. Soc. Symp. Proc.* 973 (2007) BB04–BB14.
- [83] J.M. Amarilla, K. Petrov, F. Picó, G. Avdeev, J.M. Rojo, R.M. Rojas, Sucrose-aided combustion synthesis of nanosized  $\text{LiMn}_{1.99-y}\text{Li}_y\text{M}_{0.01}\text{O}_4$  ( $M = \text{Al}^{3+}, \text{Ni}^{2+}, \text{Cr}^{3+}, \text{Co}^{3+}$ ,  $y=0.01$  and  $0.06$ ) spinels. Characterization and electrochemical behavior at 25 and at 55 °C in rechargeable lithium cells, *J. Power Sources* 191 (2009) 591–600.
- [84] S.L. Zhao, H.Y. Chen, J.B. Wen, D.X. Li, Electrochemical properties of spinel  $\text{LiCo}_x\text{Mn}_{2-x}\text{O}_4$  prepared by sol-gel process, *J. Alloys Compds* 474 (2009) 473–476.
- [85] H. Huang, C. Wang, W.K. Zhang, Y.P. Gan, L. Kang, Electrochemical study on  $\text{LiCo}_{1/6}\text{Mn}_{11/6}\text{O}_4$  as cathode material for lithium ion batteries at elevated temperature, *J. Power Sources* 184 (2008) 583–588.
- [86] T. Ohzuku, S. Takeda, M. Iwanaga, Solid-state redox potentials for  $\text{Li}[\text{Me}_{1/2}\text{Mn}_{3/2}]\text{O}_4$  (Me: 3d-transition metal) having spinel-framework structures: a series of 5 volt materials for advanced lithium-ion batteries, *J. Power Sources* 81–82 (1999) 90–94.
- [87] T.-T. Fang, H.-Y. Chung, Reassessment of the electronic-conduction behavior above Verwey-like transition of  $\text{Ni}^{2+}$ - and  $\text{Al}^{3+}$ -doped  $\text{LiMn}_2\text{O}_4$ , *J. Am. Ceram. Soc.* 91 (1) (2008) 342–345.

- [88] S. Patoux, L. Daniel, C. Bourbon, H. Lignier, C. Pagano, F. Le Cras, S. Jouanneau, S. Martinet, High voltage spinel oxides for Li-ion batteries: From the material research to the application, *J. Power Sources* 189 (2009) 344–352.
- [89] N.-E. Sung, Y.-K. Sun, S.-K. Kim, M.-S. Jang, In situ XAFS study of the effect of dopants in  $\text{Li}_{1-x}\text{Ni}_{1-(1-3x)/2}\text{Mn}_{(3+x)/2}\text{O}_4$  ( $0 \leq x \leq 1/3$ ), a Li-ion battery cathode material, *J. Electrochem. Soc.* 155 (11) (2008) A845–A850.
- [90] K.M. Shaju, P.G. Bruce, Nano- $\text{LiNi}_{0.5}\text{Mn}_{1.5}\text{O}_4$  spinel: a high power electrode for Li-ion batteries, *Dalton Trans.* 40 (2008) 5471–5475.
- [91] J. Liu, A. Manthiram, Understanding the improvement in the electrochemical properties of surface modified 5 V  $\text{LiMn}_{1.42}\text{Ni}_{0.42}\text{Co}_{0.16}\text{O}_4$  spinel cathodes in lithium-ion cells, *Chem. Mater.* 21 (8) (2009) 1695–1707.
- [92] Y.F. Yuan, H.M. Wu, S.Y. Guo, J.B. Wu, J.L. Yang, X.L. Wang, J.P. Tu, Preparation, characteristics and electrochemical properties of surface-modified  $\text{LiMn}_2\text{O}_4$  by doped  $\text{LiNi}_{0.05}\text{Mn}_{1.95}\text{O}_4$ , *Appl. Surf. Sci.* 255 (2008) 2225–2229.
- [93] J.-W. Lee, S.-M. Park, H.-J. Kim, Effect of  $\text{LiNi}_{1/2}\text{Mn}_{1/2}\text{O}_2$  coating on the electrochemical performance of Li-Mn spinel, *Electrochem. Comm.* 11 (2009) 1101–1104.
- [94] X. Li, Y. Xu, Spinel,  $\text{LiMn}_2\text{O}_4$  active material with high capacity retention, *Appl. Surf. Sci.* 253 (2007) 8592–8596.
- [95] M.B. Sahana, C. Sudakar, C. Thapa, V.M. Naik, G.W. Auner, R. Naik, K.R. Padmanabh, The effect of titanium on the lithium intercalation capacity of  $\text{V}_2\text{O}_5$  thin films, *Thin Solid Film*, in press, doi:10.1016/j.tsf.2009.04.063.
- [96] G. Li, S. Pang, L. Jiang, Z. Guo, Z. Zhang, Environmentally friendly chemical route to vanadium oxide single-crystalline nanobelts as a cathode material for lithium-ion batteries, *J. Phys. Chem. B* 110 (19) (2006) 9383–9386.
- [97] C.Q. Feng, S.Y. Wang, R. Zeng, Z.P. Guo, K. Konstantinov, H.K. Liu, Synthesis of spherical porous vanadium pentoxide and its electrochemical properties, *J. Power Sources* 184 (2008) 485–488.
- [98] V.M. Mohan, B. Hu, W. Qiu, W. Chen, Synthesis, structural, and electrochemical performance of  $\text{V}_2\text{O}_5$  nanotubes as cathode material for lithium battery, *J. Appl. Electrochem.*, in press, doi:10.1007/s10800-009-9910-6.
- [99] Y. Wang, K. Takahashi, K.H. Lee, G.Z. Cao, Nanostructures vanadium oxide electrodes for enhanced lithium-ion intercalation, *Adv. Funct. Mater.* 16 (2006) 1133–1144.
- [100] R. Benedek, M.M. Thackeray, L.H. Yang, Lithium site preference and electronic structure of  $\text{Li}_x\text{V}_3\text{O}_8$ , *Phys. Rev. B* 56 (1997) 10707–10710.
- [101] Y. Liu, X. Zhou, Y. Guo, Structure and electrochemical performance of  $\text{LiV}_3\text{O}_8$  synthesized by solid-state routine with quenching in freezing atmosphere, *Mater. Chem. Phys.* 114 (2009) 915–919.
- [102] F. Wu, L. Wang, C. Wu, Y. Bai, F. Wang, Study on  $\text{Li}_{1+x}\text{V}_3\text{O}_8$  synthesized by microwave sol-gel route, *Mater. Chem. Phys.* 115 (2009) 707–711.
- [103] J. Sun, L. Jiao, X. Wei, W. Peng, L. Liu, H. Yuan, Effect of PEG molecular weight on the crystal structure and electrochemical performance of  $\text{LiV}_3\text{O}_8$ , *J. Solid State Electrochem.*, in press, doi:10.1007/s10008-009-0829-y.
- [104] H. Liu, Y. Wang, K. Wang, Y. Wang, H. Zhou, Synthesis and electrochemical properties of single-crystalline  $\text{LiV}_3\text{O}_8$  nanorods as cathode materials for rechargeable lithium batteries, *J. Power Sources* 192 (2009) 668–673.
- [105] A.K. Padhi, K.S. Nanjundaswamy, J. Goodenough, Phospho-olivines and positive-electrode materials for rechargeable lithium batteries, *J. Electrochem. Soc.* 144 (4) (1997) 1188–1194.
- [106] A.K. Padhi, K.S. Nanjundaswamy, C. Masquelier, S. Okada, J. Goodenough, Effect of structure on the  $\text{Fe}^{3+}/\text{Fe}^{2+}$  redox couple in iron phosphates, *J. Electrochem. Soc.* 144 (5) (1997) 1609–1613.
- [107] P. Axmann, C. Stinner, M. Wohlfahrt-Mehrens, A. Mauger, F. Gendron, C.M. Julien, Nonstoichiometric  $\text{LiFePO}_4$ : defects and related properties, *Chem. Mater.* 21 (8) (2009) 1636–1644.
- [108] J. Chen, M.J. Vacchio, S. Wang, N. Chernova, P.Y. Zavalij, M.S. Whittingham, The hydrothermal synthesis and characterization of olivines and related compounds for electrochemical applications, *Solid State Ionics* 178 (2008) 1676–1693.
- [109] J. Maier, R. Amin, Defect chemistry of  $\text{LiFePO}_4$ , *J. Electrochem. Soc.* 155 (4) (2008) A339–A344.
- [110] G. Kobayashi, S.I. Nishimura, M.-S. Park, R. Kanno, M. Yashima, T. Ida, A. Yamada, Isolation of solid solution phases in size-controlled  $\text{Li}_x\text{FePO}_4$  at room temperature, *Adv. Funct. Mater.* 19 (2009) 395–403.
- [111] M. Maccario, L. Croguennec, B. Desbat, M. Couzi, F. Le Cras, L. Servant, Raman and FTIR spectroscopy investigations of carbon-coated  $\text{Li}_x\text{FePO}_4$  materials, *J. Electrochem. Soc.* 155 (12) (2008) A879–A886.
- [112] U.S. Kasavajula, C. Wang, P.E. Arce, Discharge model for  $\text{LiFePO}_4$  accounting for the solid solution range, *J. Electrochem. Soc.* 155 (11) (2008) A866–A874.
- [113] R. Dedryvère, M. Maccario, L. Croguennec, F. Le Cras, C. Delmas, D. Gonbeau, X-Ray photoelectron spectroscopy investigations of carbon-coated  $\text{Li}_x\text{FePO}_4$  materials, *Chem. Mater.* 20 (22) (2008) 7164–7170.
- [114] J.L. Allen, T.R. Jow, J. Wolfenstine, Analysis of the  $\text{FePO}_4$  to  $\text{LiFePO}_4$  phase transition, *J. Solid State Electrochem.* 12 (2008) 1031–1033.
- [115] N. Meethong, Y.-H. Kao, M. Tang, H.-Y. Huang, W.C. Carter, Y.-M. Chiang, Electrochemically induced phase transformation in nanoscale olivines  $\text{Li}_{1-x}\text{MPO}_4$  ( $M = \text{Fe}, \text{Mn}$ ), *Chem. Mater.* 20 (19) (2008) 6189–6198.
- [116] W. Sigle, R. Amin, K. Weichert, P.A. van Aken, J. Maier, Delithiation study of  $\text{LiFePO}_4$  crystals using electron energy-loss spectroscopy, *Electrochem. Solid-State Lett.* 12 (8) (2009) A151–A154.
- [117] B. Ellis, L.K. Perry, D.H. Ryan, L.F. Nazar, Small polaron hopping in  $\text{Li}_x\text{FePO}_4$  solid solutions: coupled lithium-ion and electron mobility, *J. Am. Chem. Soc.* 128 (2006) 11416–11422.
- [118] R. Amin, J. Maier, Effect of annealing on transport properties of  $\text{LiFePO}_4$ : towards a defect chemical model, *Solid State Ionics* 178 (2008) 1831–1836.
- [119] K. Zaghib, A. Mauger, F. Gendron, C.M. Julien, Magnetic studies of phospho-olivine electrodes in relation with their electrochemical performance in Li-ion batteries, *Solid State Ionics* 179 (2008) 16–23.
- [120] H.-C. Kang, D.-K. Jun, B. Jin, E.M. Jin, K.-H. Park, H.-B. Gu, K.-W. Kim, Optimized solid-state synthesis of  $\text{LiFePO}_4$  cathode materials using ball-milling, *J. Power Sources* 179 (2008) 340–346.
- [121] W. Ojczyk, J. Marzec, K. Świerczek, W. Zając, M. Molenda, R. Dziembaj, J. Molenda, Studies of selected synthesis procedures of the conducting  $\text{LiFePO}_4$ -based composite cathode materials for Li-ion batteries, *J. Power Sources* 173 (2007) 700–706.
- [122] H. Liu, J. Xie, K. Wang, Synthesis and characterization of  $\text{LiFePO}_4/(\text{C} + \text{Fe}_2\text{P})$  composite cathodes, *Solid State Ionics* 179 (2008) 1768–1771.
- [123] Y. Lin, M.X. Gao, D. Zhu, Y.F. Liu, H.G. Pan, Effects of carbon coating and iron phosphides on the electrochemical properties of  $\text{LiFePO}_4/\text{C}$ , *J. Power Sources* 184 (2008) 444–448.
- [124] H. Liu, D. Tang, The low cost synthesis of nanoparticles  $\text{LiFePO}_4/\text{C}$  composite for lithium rechargeable batteries, *Solid State Ionics* 179 (2008) 1897–1901.
- [125] M.-S. Song, D.-Y. Kim, Y.-M. Kang, Y.-I. Kim, J.-Y. Lee, H.-S. Kwon, Amphoterically effects of  $\text{Fe}_2\text{P}$  on electrochemical performance of lithium iron phosphate-carbon composite synthesized by ball-milling and microwave heating, *J. Power Sources* 180 (2008) 546–552.
- [126] T. Shiratsuchi, S. Okada, T. Doi, J.-I. Yamaki, Cathodic performance of  $\text{LiMn}_{1-x}\text{M}_x\text{PO}_4$  ( $M = \text{Ti}, \text{Mg}, \text{Zr}$ ) annealed in an inert atmosphere, *Electrochim. Acta* 54 (2009) 3145–3151.
- [127] S.-W. Kim, J. Kim, H. Gwon, K. Kang, Phase stability study of  $\text{Li}_{1-x}\text{MnPO}_4$  ( $0 \leq x \leq 1$ ) cathode for Li rechargeable battery, *J. Electrochem. Soc.* 156 (8) (2009) A635–A638.
- [128] A.V. Murugan, T. Muraliganth, A. Manthiram, One-pot microwave-hydrothermal synthesis and characterization of carbon-coated  $\text{LiMPO}_4$  ( $M = \text{Mn}, \text{Fe}, \text{and Co}$ ) cathodes, *J. Electrochem. Soc.* 156 (2) (2009) A79–A83.
- [129] N.N. Bramnik, K. Nikolowski, D.M. Trots, H. Ehrenberg, Thermal stability of  $\text{LiCoPO}_4$  cathodes, *Electrochem. Solid-State Lett.* 11 (6) (2008) A89–A93.
- [130] K.T. Lee, K.S. Lee, Electrochemical properties of  $\text{LiFe}_{0.9}\text{Mn}_{0.1}\text{PO}_4/\text{Fe}_2\text{P}$  cathode material by mechanical alloying, *J. Power Sources* 189 (2009) 435–439.
- [131] Y.-C. Chen, J.-M. Chen, C.-H. Hsu, J.-W. Yeh, H.C. Shih, Y.-S. Chang, H.-S. Sheu, Structure studies on  $\text{LiMn}_{0.25}\text{Fe}_{0.75}\text{PO}_4$  by in-situ synchrotron X-ray diffraction analysis, *J. Power Sources* 189 (2009) 790–793.
- [132] J.-K. Kim, G.S. Chauhan, J.-H. Ahn, H.-J. Ahn, Effect of synthetic conditions on the electrochemical properties of  $\text{LiMn}_{0.4}\text{Fe}_{0.6}\text{PO}_4/\text{C}$  synthesized by sol-gel technique, *J. Power Sources* 189 (2009) 391–396.
- [133] D.-W. Han, Y.-M. Kang, R.-Z. Yin, M.-S. Song, H.-S. Kwon, Effects of Fe doping on the electrochemical performance of  $\text{LiCoPO}_4/\text{C}$  composites for high power-density cathode materials, *Electrochem. Commun.* 11 (2009) 137–140.
- [134] D. Shanmukaraj, G.X. Wang, R. Murugan, H.K. Liu, Electrochemical studies on  $\text{LiFe}_{1-x}\text{Co}_x\text{PO}_4/\text{carbon}$  composite cathode materials synthesized by citrate gel technique for lithium-ion batteries, *Mater. Sci. Eng. B* 149 (2008) 93–98.
- [135] D.-H. Baek, J.-K. Kim, Y.-J. Shin, G.S. Chauhan, J.-H. Ahn, K.-W. Kim, Effect of firing temperature on the electrochemical performance of  $\text{LiMn}_{0.4}\text{Fe}_{0.6}\text{PO}_4/\text{C}$  materials prepared by mechanical activation, *J. Power Sources* 189 (2009) 59–65.
- [136] G. Kobayashi, A. Yamada, S.-I. Nishimura, R. Kanno, Y. Kobayashi, S. Seki, Y. Ohno, H. Miyashiro, Shift of redox potential and kinetics in  $\text{Li}_x(\text{Mn}_y\text{Fe}_{1-y})\text{PO}_4$ , *J. Power Sources* 189 (2009) 397–401.
- [137] M. Kopeec, A. Yamada, G. Kobayashi, S. Nishimura, R. Kanno, A. Mauger, F. Gendron, C.M. Julien, Structural and magnetic properties of  $\text{Li}_x(\text{Mn}_y\text{Fe}_{1-y})\text{PO}_4$  electrode materials for Li-ion batteries, *J. Power Sources* 189 (2009) 1154–1163.
- [138] M.-R. Yang, W.-H. Ke, The doping effect on the electrochemical properties of  $\text{LiFe}_{0.95}\text{Mn}_{0.05}\text{PO}_4$  ( $M = \text{Mg}^{2+}, \text{Ni}^{2+}, \text{Al}^{3+}, \text{or V}^{3+}$ ) as cathode materials for lithium-ion cells, *J. Electrochem. Soc.* 155 (10) (2008) A729–A732.
- [139] Y. Lu, J. Shi, Z. Guo, Q. Tong, W. Huang, B. Li, Synthesis of  $\text{LiFe}_{1-x}\text{Ni}_x\text{PO}_4/\text{C}$  composites and their electrochemical performance, *J. Power Sources* 194 (2009) 786–793.
- [140] G. Chen, J.D. Wilcox, T.J. Richardson, Improving the performance of lithium manganese phosphate through divalent cation substitution, *Electrochem. Solid-State Lett.* 11 (11) (2008) A190–A194.
- [141] X.-H. Liu, T. Saito, T. Doi, S. Okada, J.-I. Yamaki, Electrochemical properties of rechargeable aqueous lithium ion batteries with an olivine-type cathode and a Nasicon-type anode, *J. Power Sources* 189 (2009) 706–710.
- [142] Y. Zhang, C.S. Sun, Z. Zhou, Sol-gel preparation and electrochemical performance of  $\text{LiFe}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3}\text{PO}_4/\text{C}$  composites with core-shell nanostructure, *Electrochem. Commun.* 11 (2009) 1183–1186.
- [143] X.J. Wang, X.Q. Yu, H. Li, X.Q. Yang, J. McBreen, X.J. Huang, Li-storage in  $\text{LiFe}_{1/4}\text{Mn}_{1/4}\text{Co}_{1/4}\text{Ni}_{1/4}\text{PO}_4$  solid solution, *Electrochem. Commun.* 10 (2008) 1347–1350.
- [144] K.-W. Nam, X.-J. Wang, W.-S. Yoon, H. Li, X. Huang, O. Haas, J. Bai, X.-Q. Yang, In situ x-ray absorption and diffraction studies of carbon coated  $\text{LiFe}_{1/4}\text{Mn}_{1/4}\text{Co}_{1/4}\text{Ni}_{1/4}\text{PO}_4$  cathode during first charge, *Electrochem. Commun.* 11 (2009) 913–916.
- [145] X. Zhu, Y. Liu, L. Geng, L. Chen, H. Liu, M. Cao, Synthesis and characteristics of  $\text{Li}_3\text{V}_2(\text{PO}_4)_3$  as cathode materials for lithium-ion batteries, *Solid State Ionics* 179 (2008) 1679–1682.
- [146] Q. Chen, J. Wang, Z. Tang, W. He, H. Shao, J. Zhang, Electrochemical performance of the carbon coated  $\text{Li}_3\text{V}_2(\text{PO}_4)_3$  cathode material synthesized by a sol-gel method, *Electrochim. Acta* 52 (2007) 5251–5257.

- [147] H. Huang, T. Faulkner, J. Barker, M.Y. Saidi, Lithium metal phosphates, power and automotive applications, *J. Power Sources* 189 (2009) 748–751.
- [148] F. Yu, J. Zhang, Y. Yang, G. Song, Preparation and electrochemical performance of  $\text{Li}_3\text{V}_2(\text{PO}_4)_3/\text{C}$  cathode material by spray-drying and carbothermal method, *J. Solid State Electrochem.*, in press, doi:10.1007/s10008-009-0882-6.
- [149] J. Hong, C.S. Wang, X. Chen, S. Upreti, M.S. Whittingham, Vanadium modified  $\text{LiFePO}_4$  cathode for Li-ion batteries, *Electrochem. Solid-State Lett.* 12 (2) (2009) A33–A38.
- [150] C.S. Sun, Z. Zhou, Z.G. Xu, D.G. Wang, J.P. Wei, X.K. Bian, J. Yan, Improved high-rate charge/discharge performances of  $\text{LiFePO}_4/\text{C}$  via V-doping, *J. Power Sources* 193 (2009) 841–845.
- [151] J.C. Arrebola, A. Caballero, J.L. Gómez-Cámer, L. Hernán, J. Morales, L. Sánchez, Combining 5V  $\text{LiNi}_{0.5}\text{Mn}_{1.5}\text{O}_4$  spinel and Si nanoparticles for advanced Li-ion batteries, *Electrochem. Commun.* 11 (2009) 1061–1064.
- [152] R. Ruffo, C. Wessells, R.A. Huggins, Y. Cui, Electrochemical behavior of  $\text{LiCoO}_2$  as aqueous lithium-ion battery electrodes, *Electrochem. Commun.* 11 (2009) 247–249.
- [153] H. Nakano, K. Dokko, S. Koizumi, H. Tanna, K. Kanamura, Hydrothermal synthesis of carbon-coated  $\text{LiFePO}_4$  and its application to lithium polymer battery, *J. Electrochem. Soc.* 155 (12) (2008) A909–A914.
- [154] P. He, X. Zhang, Y.-G. Wang, L. Cheng, Y.-Y. Xia, Lithium-ion intercalation behavior of  $\text{LiFePO}_4$  in aqueous and nonaqueous electrolyte solutions, *J. Electrochem. Soc.* 155 (2) (2008) A144–A150.
- [155] X. Zhi, G. Liang, L. Wang, X. Ou, J. Zhang, J. Cui, The cycling performance of  $\text{LiFePO}_4/\text{C}$  cathode materials, *J. Power Sources* 189 (2009) 779–782.
- [156] K. Wang, R. Cai, T. Yuan, X. Yu, R. Ran, Z. Shao, Process investigation, electrochemical characterization, optimization of  $\text{LiFePO}_4/\text{C}$  composite from mechanical activation using sucrose as carbon source, *Electrochim. Acta* 54 (2009) 2861–2868.
- [157] S. Lim, C.S. Yoon, J. Cho, Synthesis of nanowire and hollow  $\text{LiFePO}_4$  cathodes for high-performance lithium batteries, *Chem. Mater.* 20 (14) (2008) 4560–4564.
- [158] J.-M. Chen, C.-H. Hsu, Y.-R. Lin, M.-H. Hsiao, G.T.-K. Fey, High-power  $\text{LiFePO}_4$  cathode materials with a continuous nano carbon network for lithium-ion batteries, *J. Power Sources* 184 (2008) 498–502.
- [159] B. Zhao, Y. Jiang, H. Zhang, H. Tao, M. Zhong, Z. Jiao, Morphology and electrical properties of carbon coated  $\text{LiFePO}_4$  cathode materials, *J. Power Sources* 189 (2009) 462–466.
- [160] Y.Z. Dong, Y.M. Zhao, Y.H. Chen, Z.F. He, Q. Kuang, Optimized carbon-coated  $\text{LiFePO}_4$  cathode material for lithium-ion batteries, *Mater. Chem. Phys.* 115 (2009) 245–250.
- [161] Z.-R. Chang, H.-J. Lv, H.-W. Tang, H.-J. Li, X.-Z. Yuan, H. Wang, Synthesis and characterization of high-density  $\text{LiFePO}_4/\text{composites}$  as cathode materials for lithium-ion batteries, *Electrochim. Acta* 54 (2009) 4595–4599.
- [162] Y. Yang, X.-Z. Liao, Z.-F. Ma, B.-F. Wang, L. He, Y.-S. He, Superior high-rate cycling performance of  $\text{LiFePO}_4/\text{C-PPy}$  composite at 55 °C, *Electrochem. Commun.* 11 (2009) 1277–1280.
- [163] Y. Zhao, D. Xia, Y. Li, C. Yu, Investigation of high-rate spherical  $\text{LiCoO}_2$  with mesoporous structure via self-assembly in microemulsion, *Electrochem. Solid-State Lett.* 11 (3) (2008) A30–A33.
- [164] M. Okubo, E. Hosono, T. Kudo, H.S. Zhou, I. Honma, Size effect on electrochemical property of nanocrystalline  $\text{LiCoO}_2$  synthesized from rapid thermal annealing method, *Solid State Ionics* 180 (2008) 612–615.
- [165] W. Kim, J.-J. Cho, Y. Kang, D.-W. Kim, Study on cycling performances of lithium-ion polymer cells assembled by in situ chemical cross-linking with star-shaped siloxane acrylate, *J. Power Sources* 178 (2008) 837–841.
- [166] E.-G. Shim, T.-H. Nam, J.-G. Kim, H.-S. Kim, S.-I. Moon, Diphenyloctyl phosphate as a flame-retardant additive in electrolyte for Li-ion batteries, *J. Power Sources* 175 (2008) 533–539.
- [167] J.-T. Lee, Y.-J. Chu, X.-W. Peng, F.-M. Wang, C.-R. Yang, C.-C. Li, A novel and efficient water-based composite binder for  $\text{LiCoO}_2$  cathodes in lithium-ion batteries, *J. Power Sources* 173 (2007) 985–989.
- [168] H.T. Kuo, T.S. Chan, N.C. Bagkar, R.S. Liu, C.H. Shen, D.S. Shy, X.K. Xing, J.-F. Lee, Effect of LiI amount to enhance the electrochemical performance of carbon-coated  $\text{LiFePO}_4$ , *Electrochem. Solid-State Lett.* 12 (6) (2009) A111–A114.
- [169] C. Zhu, H. Cheng, Y. Yang, Electrochemical characterization of two types of PEO-based polymer electrolytes with room-temperature ionic liquids, *J. Electrochem. Soc.* 155 (8) (2008) A569–A575.
- [170] G.L. Yang, A.F. Jalbout, Y. Xu, H.Y. Yu, X.G. He, H.M. Xie, R.S. Wang, Effect of polyacenic semiconductors on the performance of olivine  $\text{LiFePO}_4$ , *Electrochem. Solid-State Lett.* 11 (8) (2008) A125–A128.
- [171] F. Yu, J. Zhang, Y. Yang, G. Song, Preparation and characterization of mesoporous  $\text{LiFePO}_4/\text{C}$  microsphere by spray drying assisted template method, *J. Power Sources* 189 (2009) 794–797.
- [172] H. Xie, Z. Tang, Z. Li, Y. He, Y. Liu, H. Wang, PVDF-HFP composite polymer electrolyte with excellent electrochemical properties for Li-ion batteries, *J. Solid State Electrochem.* 12 (2008) 1497–1502.
- [173] J. Liu, R. Jiang, X. Wang, T. Huang, A. Yu, The defect chemistry of  $\text{LiFePO}_4$  prepared by hydrothermal method at different pH values, *J. Power Sources* 194 (2009) 536–540.
- [174] Z. Liu, X. Zhang, L. Hong, Preparation and electrochemical properties of spherical  $\text{LiFePO}_4$  and  $\text{LiFe}_{0.9}\text{Mg}_{0.1}\text{PO}_4$  cathode materials for lithium rechargeable batteries, *J. Appl. Electrochem.*, in press, doi:10.1007/s10800-009-9931-1.
- [175] M.L. Marcinek, J.W. Wilcox, M.M. Doeff, R.M. Kostecki, Microwave plasma chemical vapor deposition of carbon coatings on  $\text{LiNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}\text{O}_2$  for Li-ion battery composite cathodes, *J. Electrochem. Soc.* 156 (1) (2009) A48–A51.
- [176] H.-S. Kim, K. Kim, S.I. Moon, I.-J. Kim, H.-B. Gu, A study on carbon-coated  $\text{LiNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}\text{O}_2$  cathode material for lithium secondary batteries, *J. Solid State Electrochem.* 12 (2008) 867–872.
- [177] Y. Huang, J. Chen, J. Ni, H. Zhou, X. Zhang, A modified  $\text{ZrO}_2$ -coating process to improve electrochemical performance of  $\text{LiNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}\text{O}_2$ , *J. Power Sources* 188 (2009) 538–545.
- [178] G. Li, Z. Yang, W. Yang, Effect of  $\text{FePO}_4$  coating on electrochemical and safety performance of  $\text{LiCoO}_2$  as cathode material for Li-ion batteries, *J. Power Sources* 183 (2008) 741–748.
- [179] J.H. Park, S.-Y. Lee, J.H. Ki, S. Ahn, J.-S. Park, Y.U. Jeong, Effect of conducting additives on the properties of composite cathodes for lithium-ion batteries, *J. Solid State Electrochem.*, in press, doi:10.1007/s10008-009-0814-5.
- [180] H.-H. Chang, C.-C. Chang, C.-Y. Su, H.-C. Wu, M.-H. Yang, N.-L. Wu, Effects of  $\text{TiO}_2$  coating on high-temperature cycle performance of  $\text{LiFePO}_4$ -based lithium-ion batteries, *J. Power Sources* 185 (2008) 466–472.
- [181] K.M. Shaju, P.G. Bruce, A stoichiometric nano- $\text{LiMn}_2\text{O}_4$  spinel electrode exhibiting high power and stable cycling, *Chem. Mater.* 20 (17) (2008) 5557–5562.
- [182] H. Şahan, H. Göktepe, Ş. Patat, A. Ülgen, The effect of LBO coating method on electrochemical performance of  $\text{LiMn}_2\text{O}_4$  cathode material, *Solid State Ionics* 178 (2008) 1837–1842.
- [183] S. Lim, J. Cho, PVP-Assisted  $\text{ZrO}_2$  coating on  $\text{LiMn}_2\text{O}_4$  spinel cathode nanoparticles prepared by  $\text{MnO}_2$  nanowire templates, *Electrochem. Commun.* 10 (2008) 1478–1481.
- [184] T. Okumura, T. Fukutsuka, Y. Uchimoto, K. Amezawa, S. Kobayashi, Cathode having high rate performance for a secondary Li-ion cell surface-modified by aluminum oxide nanoparticles, *J. Power Sources* 189 (2009) 471–475.
- [185] N.N. Sinha, N. Munichandraiah, Synthesis and characterization of submicron size particles of  $\text{LiMn}_2\text{O}_4$  by microemulsion route, *J. Solid State Electrochem.* 12 (2008) 1619–1627.
- [186] T.-F. Yi, Y.-R. Zhu, R.-S. Zhu, Density functional theory study of lithium intercalation for 5V  $\text{LiNi}_{0.5}\text{Mn}_{1.5}\text{O}_4$  cathode materials, *Solid State Ionics* 180 (2009) 2132–2136.
- [187] R. Thirunakaran, A. Sivashanmugam, S. Gopukumar, C.W. Dunnill, D.H. Gregory, Phthalic acid assisted nano-sized spinel  $\text{LiMn}_2\text{O}_4$  and  $\text{LiCr}_x\text{Mn}_{2-x}\text{O}_4$  ( $x=0.00-0.40$ ) via sol-gel synthesis and its electrochemical behaviour for use in Li-ion-batteries, *Mater. Res. Bull.* 43 (2008) 2119–2129.
- [188] M.V. Reddy, S. Sundar Manoharan, J. John, B. Singh, G.V.S. Rao, B.V.R. Chowdari, Synthesis, characterization, and electrochemical cycling behavior of the Rudoped spinel,  $\text{Li}[\text{Mn}_{2-x}\text{Ru}_x]\text{O}_4$  ( $x=0, 0.1, \text{ and } 0.25$ ), *J. Electrochem. Soc.* 156 (8) (2009) A652–A660.
- [189] S.H. Ju, H.C. Jang, Y.C. Kang,  $\text{LiCo}_{1-x}\text{Al}_x\text{O}_2$  ( $0 \leq x \leq 0.05$ ) cathode powders prepared from the nanosized  $\text{Co}_{1-x}\text{Al}_x\text{O}_y$  precursor powders, *Mater. Chem. Phys.* 112 (2008) 536–541.
- [190] S.-M. Eo, E. Cha, D.-W. Kim, Effect of an inorganic additive on the cycling performances of lithium-ion polymer cells assembled with polymer-coated separators, *J. Power Sources* 189 (2009) 766–770.
- [191] W. Guoping, Z. Qingtang, Y. Zuolong, Q. Meizheng, The effect of different kinds of nano-carbon conductive additives in lithium ion batteries on the resistance and electrochemical behavior of the  $\text{LiCoO}_2$  composite cathodes, *Solid State Ionics* 179 (2008) 263–268.
- [192] G.T.-K. Fey, C.-S. Chang and T.P. Kumar, Synthesis and surface treatment of  $\text{LiNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}\text{O}_2$  cathode materials for Li-ion batteries, *J. Solid State Electrochem.*, in press, doi:10.1007/s10008-008-0772-3.
- [193] K. Kim, S. Ahn, H.-S. Kim, H.K. Liu, Electrochemical and thermal properties of 2,4,6-tris (trifluoromethyl)-1,3,5-triazine as a flame retardant additive in Li-ion batteries, *Electrochim. Acta* 54 (2009) 2259–2265.
- [194] B. Lin, Z. Wen, Z. Gu, S. Huang, Morphology and electrochemical performance of  $\text{Li}[\text{Ni}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}]\text{O}_2$  cathode material by a slurry spray drying method, *J. Power Sources* 175 (2008) 564–569.
- [195] F. Wu, M. Wang, Y. Su, S. Chen, B. Xu, Effect of  $\text{TiO}_2$ -coating on the electrochemical performances of  $\text{LiCo}_{1/3}\text{Ni}_{1/3}\text{Mn}_{1/3}\text{O}_2$ , *J. Power Sources* 191 (2009) 628–632.
- [196] A. Abdel-Ghany, K. Zaghbi, A. Mauger, F. Gendron, A.E. Eid, H. Abbas, A.M. Hashem, C.V. Ramana, C.M. Julien, Electrochemical features of Li-Ni-Mn-Co oxides, *Mater. Res. Soc. Symp. Proc.* 973 (2007) BB04–05.
- [197] M. Konarova, I. Taniguchi, Preparation of  $\text{LiFePO}_4/\text{C}$  composite powders by ultrasonic spray pyrolysis followed by heat treatment and their electrochemical properties, *Mater. Res. Bull.* 43 (2008) 3305–3317.
- [198] J.-K. Kim, G. Cheruvally, J.-H. Ahn, Electrochemical properties of  $\text{LiFePO}_4/\text{C}$  synthesized by mechanical activation using sucrose as carbon source, *J. Solid State Electrochem.* 12 (2008) 799–805.
- [199] M.M. Doeff, J.D. Wilcox, R. Yu, A. Aumentado, M. Marcinek, R. Kostecki, Impact of carbon structure and morphology on the electrochemical performance of  $\text{LiFePO}_4/\text{C}$  composites, *J. Solid State Electrochem.* 12 (2008) 995–1001.
- [200] N. Recham, M. Armand, L. Laffont, J.-M. Tarascon, Eco-efficient synthesis of  $\text{LiFePO}_4$  with different morphologies for Li-ion batteries, *Electrochem. Solid-State Lett.* 12 (2) (2009) A39–A44.
- [201] A. Fedorková, H.-D. Wiemhöfer, R. Oriňáková, A. Oriňák, M.C. Stan, M. Winter, D. Kaniánsky, A.N. Alejos, Improved lithium exchange at  $\text{LiFePO}_4$  cathode particles by coating with composite polypyrrole-polyethylene glycol layers, *J. Solid State Electrochem.*, in press, doi:10.1007/s10008-008-0756-3.
- [202] Y.-H. Nien, J.R. Carey, J.-S. Chen, Physical and electrochemical properties of  $\text{LiFePO}_4/\text{C}$  composite cathode prepared from various polymer-containing precursors, *J. Power Sources* 193 (2009) 822–827.



- [203] H.H. Sumathipala, J. Hassoun, S. Panero, B. Scrosati, Li-LiFePO<sub>4</sub> rechargeable polymer battery using dual composite polymer electrolytes, *J. Appl. Electrochem.* 38 (2008) 39–42.
- [204] D.-H. Kim, J. Kim, Synthesis of LiFePO<sub>4</sub> nanoparticles in polyol medium and their electrochemical properties, *Electrochem. Solid-State Lett.* 9 (9) (2006) A439–A442.
- [205] X. Li, W. Wang, C. Shi, H. Wang, Y. Xing, Structural and electrochemical characterization of LiFePO<sub>4</sub>/C prepared by a sol-gel route with long- and short-chain carbon sources, *J. Solid State Electrochem.* 13 (2009) 921–926.
- [206] J.-C. Zheng, X.-H. Li, Z.-X. Wang, H.-J. Guo, S.-Y. Zhou, LiFePO<sub>4</sub> with enhanced performance synthesized by a novel synthetic route, *J. Power Sources* 184 (2008) 574–577.
- [207] Z. Wen, S. Huang, X. Yang, B. Lin, High rate electrode materials for lithium ion batteries, *Solid State Ionics* 179 (2008) 1800–1805.
- [208] L.-Z. Fan, X.-L. Wang, F. Long, All-solid-state polymer electrolyte with plastic crystal materials for rechargeable lithium-ion battery, *J. Power Sources* 189 (2009) 775–778.
- [209] Y. Idemoto, T. Matsui, Thermodynamic stability, crystal structure, and cathodic performance of Li<sub>x</sub>(Mn<sub>1/3</sub>Co<sub>1/3</sub>Ni<sub>1/3</sub>)O<sub>2</sub> depend on the synthetic process and Li content, *Solid State Ionics* 179 (2008) 625–635.
- [210] S.-K. Hu, G.-H. Cheng, M.-Y. Cheng, B.-J. Hwang, R. Santhanam, Cycle life improvement of ZrO<sub>2</sub>-coated spherical LiMn<sub>1/3</sub>Co<sub>1/3</sub>Ni<sub>1/3</sub>O<sub>2</sub> depend on the synthetic process and Li content cathode material for lithium-ion batteries, *J. Power Sources* 188 (2009) 564–569.
- [211] P. Albertus, J. Christensen, J. Newman, Experiments on and modeling of positive electrodes with multiple active materials for lithium-ion batteries, *J. Electrochem. Soc.* 156 (7) (2009) A606–A618.
- [212] J.F. Whitacre, K. Zaghbi, W.C. West, B.V. Ratnakumar, Dual active material composite cathode structures for Li-ion batteries, *J. Power Sources* 177 (2008) 528–536.
- [213] S.-B. Kim, K.J. Lee, W.J. Choi, W.-S. Kim, I.C. Jang, H.H. Lim, Y.S. Lee, Preparation and cycle performance at high temperature for Li(Ni<sub>0.5</sub>Co<sub>0.2</sub>Mn<sub>0.3</sub>)<sub>2</sub> coated with LiFePO<sub>4</sub>, *J. Solid State Electrochem.*, in press, doi:10.1007/s10008-009-0873-7.
- [214] S.-H. Kang, M.M. Thackeray, Enhancing the rate capability of high capacity xLi<sub>2</sub>MnO<sub>3</sub>-(1-x)LiMO<sub>2</sub> (M=Mn, Ni, Co) electrodes by Li-Ni-PO<sub>4</sub> treatment, *Electrochem. Commun.* 11 (2009) 748–751.
- [215] Z. Su, S.H. Ye, T.Y. Yan, X.P. Gao, P.W. Shen, Synthesis and electrochemical properties of nanosized Li<sub>2</sub>MnO<sub>3</sub> as cathode materials for lithium batteries, *J. Electrochem. Soc.* 155 (11) (2008) A839–A844.
- [216] T.A. Arunkumar, E. Alvarez, A. Manthiram, Chemical and structural instability of the chemically delithiated (1-z)Li[Li<sub>1/3</sub>Mn<sub>2/3</sub>]O<sub>2</sub>-(z)Li[Co<sub>1-y</sub>Ni<sub>y</sub>]O<sub>2</sub> (0 ≤ y ≤ 1 and 0 ≤ z ≤ 1) solid solution cathodes, *J. Mater. Chem.* 18 (2008) 190–198.
- [217] S. Sivaprakash, S.B. Majumder, R.S. Katiyar, Investigations on 0.5Li(Ni<sub>0.8</sub>Co<sub>0.15</sub>Zr<sub>0.05</sub>)O<sub>2</sub>-0.5Li(Li<sub>1/3</sub>Mn<sub>2/3</sub>)O<sub>2</sub> cathode for Li rechargeable batteries, *J. Electrochem. Soc.* 156 (4) (2009) A328–A333.
- [218] M.M. Thackeray, S.-H. Kang, C.S. Johnson, J.T. Vaughey, R. Benedek, S.A. Hackney, Li<sub>2</sub>MnO<sub>3</sub>-stabilized LiMO<sub>2</sub> (M=Mn, Ni, Co) electrodes for lithium-ion batteries, *J. Mater. Chem.* 17 (2007) 4012–4016.
- [219] C.S. Johnson, N. Li, C. Lefief, J.T. Vaughey, M.M. Thackeray, Synthesis, characterization and electrochemistry of lithium battery electrodes: xLi<sub>2</sub>MnO<sub>3</sub>-(1-x)LiMn<sub>0.333</sub>Ni<sub>0.333</sub>Co<sub>0.333</sub>O<sub>2</sub> (0 ≤ x ≤ 0.7), *Chem. Mater.* 20 (19) (2008) 6095–6106.
- [220] G.-Y. Kim, S.-B. Yi, Y.J. Park, H.-G. Kim, Electrochemical behaviors of Li[Li<sub>(1-x)/3</sub>Mn<sub>(2-x)/3</sub>Ni<sub>x/3</sub>Co<sub>x/3</sub>]O<sub>2</sub> cathode series (0 < x < 1) synthesized by sucrose combustion process for high capacity lithium ion batteries, *Mater. Res. Bull.* 43 (2008) 3543–3552.
- [221] X.-J. Guo, Y.-X. Li, M. Zheng, J.-M. Zheng, J. Li, Z.-L. Gong, Y. Yang, Structural and electrochemical characterization of xLi[Li<sub>1/3</sub>Mn<sub>2/3</sub>]O<sub>2</sub>-(1-x)Li[Ni<sub>1/3</sub>Mn<sub>1/3</sub>Co<sub>1/3</sub>]O<sub>2</sub> (0 ≤ x ≤ 0.9) as cathode materials for lithium ion batteries, *J. Power Sources* 184 (2008) 414–419.
- [222] S.-H. Kang, M.M. Thackeray, Stabilization of xLi<sub>2</sub>MnO<sub>3</sub>-(1-x)LiMO<sub>2</sub> electrode surfaces (M=Mn, Ni, Co) with mildly acidic, fluorinated solutions, *J. Electrochem. Soc.* 155 (4) (2008) A269–A275.
- [223] J. Gao, A. Manthiram, Eliminating the irreversible capacity loss of high capacity layered Li[Li<sub>0.2</sub>Mn<sub>0.54</sub>Ni<sub>0.13</sub>Co<sub>0.13</sub>]O<sub>2</sub> cathode by blending with other lithium insertion hosts, *J. Power Sources* 191 (2009) 644–647.
- [224] J.-H. Lim, H. Bang, K.-S. Lee, K. Amine, Y.-K. Sun, Electrochemical characterization of Li<sub>2</sub>MnO<sub>3</sub>-Li[Ni<sub>1/3</sub>Co<sub>1/3</sub>Mn<sub>1/3</sub>]O<sub>2</sub>-LiNiO<sub>2</sub> cathode synthesized via co-precipitation for lithium secondary batteries, *J. Power Sources* 189 (2009) 571–575.
- [225] N.V. Kosova, E.T. Devyatkina, V.V. Kaichev, LiMn<sub>2</sub>O<sub>4</sub> and LiCoO<sub>2</sub> composite cathode materials obtained by mechanical activation, *Russ. J. Electrochem.* 45 (3) (2009) 277–285.
- [226] K.-W. Nam, W.-S. Yoon, H. Shin, K.Y. Chung, S. Choi, X.-Q. Yang, In situ X-ray diffraction studies of mixed LiMn<sub>2</sub>O<sub>4</sub>-LiNi<sub>1/3</sub>Co<sub>1/3</sub>Mn<sub>1/3</sub>O<sub>2</sub> composite cathode in Li-ion cells during charge-discharge cycling, *J. Power Sources* 192 (2009) 652–659.
- [227] S.K. Jeong, J.S. Shin, K.S. Nahm, T.P. Kumar, A.M. Stephan, Electrochemical studies on cathode blends of LiMn<sub>2</sub>O<sub>4</sub> and Li[Li<sub>1/15</sub>Ni<sub>1/5</sub>Co<sub>2/5</sub>Mn<sub>1/3</sub>]O<sub>2</sub>, *Mater. Chem. Phys.* 111 (2008) 213–217.
- [228] K.M. Kim, S.H. Lee, S. Kim, Y.-G. Lee, Electrochemical properties of mixed cathode consisting of μm-sized LiCoO<sub>2</sub> and nm-sized Li[Co<sub>0.1</sub>Ni<sub>0.15</sub>Li<sub>0.25</sub>Mn<sub>0.55</sub>]O<sub>2</sub> in lithium rechargeable batteries, *J. Appl. Electrochem.* 39 (2009) 1487–1495.
- [229] K.-S. Lee, S.-T. Myung, H. Bang, K. Amine, D.-W. Kim, Y.-K. Sun, Effect of protecting metal oxide (Co<sub>3</sub>O<sub>4</sub>) layer on electrochemical properties of spinel Li<sub>1.1</sub>Mn<sub>1.9</sub>O<sub>4</sub> as a cathode material for lithium battery applications, *J. Power Sources* 189 (2009) 494–498.
- [230] X.-R. Deng, G.-R. Hu, K. Du, Z.-D. Peng, X.-G. Gao, Y.-N. Yang, Synthesis and electrochemical properties of Co,Mn-coated LiNiO<sub>2</sub> lithium-ion battery cathode materials, *Mater. Chem. Phys.* 109 (2008) 469–474.
- [231] J. Gao, J. Kim, A. Manthiram, High capacity Li[Li<sub>0.2</sub>Mn<sub>0.54</sub>Ni<sub>0.13</sub>Co<sub>0.13</sub>]O<sub>2</sub>-V<sub>2</sub>O<sub>5</sub> composite cathodes with low irreversible capacity loss for lithium ion batteries, *Electrochem. Commun.* 11 (2009) 84–86.
- [232] S. Stewart, P. Albertus, V. Srinivasan, I. Plitz, N. Pereira, G. Amatucci, J. Newman, Optimizing the performance of lithium titanate spinel paired with activated carbon or iron phosphate, *J. Electrochem. Soc.* 155 (3) (2008) A253–A261.
- [233] H.E. Park, I.W. Seong, W.Y. Yoon, Electrochemical behaviors of wax coated Li powder/Li<sub>4</sub>Ti<sub>5</sub>O<sub>12</sub> cells, *J. Power Sources* 189 (2009) 499–502.
- [234] J. Shu, Electrochemical behavior and stability of Li<sub>4</sub>Ti<sub>5</sub>O<sub>12</sub> in a broad voltage window, *J. Solid State Electrochem.* 13 (2009) 1535–1539.
- [235] H. Kitaura, A. Hayashi, K. Tadanaga, M. Tatsumisago, High-rate performance of all-solid-state lithium secondary batteries using Li<sub>4</sub>Ti<sub>5</sub>O<sub>12</sub> electrode, *J. Power Sources* 189 (2009) 145–148.
- [236] H. Kitaura, A. Hayashi, K. Tadanaga, M. Tatsumisago, Electrochemical analysis of Li<sub>4</sub>Ti<sub>5</sub>O<sub>12</sub> electrode in all-solid-state lithium secondary batteries, *J. Electrochem. Soc.* 156 (2) (2009) A114–A119.
- [237] K. Takada, N. Ohta, L. Zhang, K. Fukuda, I. Sakaguchi, R. Ma, M. Osada, T. Sasaki, Interfacial modification for high-power solid-state lithium batteries, *Solid State Ionics* 179 (2008) 1333–1337.
- [238] D.-Q. Liu, X.-Q. Liu, Z.-Z. He, The elevated temperature performance of LiMn<sub>2</sub>O<sub>4</sub> coated with Li<sub>4</sub>Ti<sub>5</sub>O<sub>12</sub> for lithium ion battery, *Mater. Chem. Phys.* 105 (2007) 362–366.
- [239] T.-F. Yi, J. Shu, Y.-R. Zhu, A.-N. Zhou, R.-S. Zhu, Structure and electrochemical performance of Li<sub>4</sub>Ti<sub>5</sub>O<sub>12</sub>-coated LiMn<sub>1.4</sub>Ni<sub>0.4</sub>Cr<sub>0.2</sub>O<sub>4</sub> spinel as 5V materials, *Electrochem. Commun.* 11 (2009) 91–94.
- [240] H.-W. Lu, L. Yu, W. Zeng, Y.-S. Li, Z.-W. Fu, Fabrication and electrochemical properties of three-dimensional structure of LiCoO<sub>2</sub> fibers, *Electrochem. Solid-State Lett.* 11 (8) (2008) A140–A144.
- [241] C.P. Fonseca, M.A. Bellei, F.A. Amaral, S.C. Canobre, S. Neves, Synthesis and characterization of LiM<sub>x</sub>Mn<sub>2-x</sub>O<sub>4</sub> (M=Al, Bi and Cs ions) films for lithium ion batteries, *Energy Convers. Manage.* 50 (2009) 1556–1562.
- [242] J.B. Heo, S.B. Lee, S.H. Cho, J. Kim, S.H. Park, Y.S. Lee, Synthesis and electrochemical characterizations of dual doped Li<sub>1.05</sub>Fe<sub>0.997</sub>Co<sub>0.003</sub>PO<sub>4</sub>, *Mater. Lett.* 63 (2009) 581–583.
- [243] M.Y. Song, I.H. Kwon, J. Song, S. Shim, Electrochemical properties of Li<sub>1-x/2</sub>(Ni<sub>1-y/2</sub>Fe<sub>y/2</sub>)<sub>1+x/2</sub>O<sub>2</sub> synthesized by the combustion method in an air atmosphere, *J. Appl. Electrochem.* 39 (2009) 617–625.
- [244] M.Y. Song, I.H. Kwon, Electrochemical properties of LiNi<sub>1-y</sub>Fe<sub>y</sub>O<sub>2</sub> synthesized by the combustion method in O<sub>2</sub>, *J. Alloys Compd.*, in press, doi:10.1016/j.jallcom.2009.04.155.
- [245] M. Tabuchi, Y. Nabeshima, K. Ado, M. Shikano, K.H. Kageyama, K. Tatsumi, Material design concept for Fe-substituted Li<sub>2</sub>MnO<sub>3</sub>-based positive electrodes, *J. Power Sources* 174 (2007) 554–559.
- [246] M. Tabuchi, Y. Nabeshima, M. Shikano, K. Ado, H. Kageyama, K. Tatsumi, Optimizing chemical composition and preparation conditions for Fe-substituted Li<sub>2</sub>MnO<sub>3</sub> positive electrode material, *J. Electrochem. Soc.* 154 (7) (2007) A638–A648.
- [247] S. Rajakumar, R. Thirunakaran, A. Sivashanmugam, J.-I. Yamaki, S. Gopukumar, Electrochemical behavior of LiM<sub>0.25</sub>Ni<sub>0.25</sub>Mn<sub>1.5</sub>O<sub>4</sub> as 5V cathode materials for lithium rechargeable, *J. Electrochem. Soc.* 156 (3) (2009) A246–A252.
- [248] J.D. Wilcox, S. Patoux, M.M. Doeff, Structure and electrochemistry of LiNi<sub>1/3</sub>Co<sub>1/3-y</sub>M<sub>y</sub>Mn<sub>1/3</sub>O<sub>2</sub> (M=Ti, Al, Fe) positive electrode materials, *J. Electrochem. Soc.* 156 (3) (2009) A192–A198.
- [249] R. Alcántara, G. Ortiz, J.L. Tirado, R. Stoyanova, E. Zhecheva, Sv. Ivanova, Fe<sup>3+</sup> and Ni<sup>3+</sup> impurity distribution and electrochemical performance of LiCoO<sub>2</sub> electrode materials for lithium ion batteries, *J. Power Sources* 194 (2009) 494–501.
- [250] H. Wang, H. Xia, M.O. Lai, L. Lu, Enhancements of rate capability and cyclic performance of spinel-LiNi<sub>0.5</sub>Mn<sub>1.5</sub>O<sub>4</sub> by trace Ru-doping, *Electrochem. Commun.* 11 (2009) 1539–1542.
- [251] Y. Wang, Y. u Yang, X. Hu, Y. Yang, H. Shao, Electrochemical performance of Ru-doped LiFePO<sub>4</sub>/C cathode material for lithium-ion batteries, *J. Alloys Compd.* 481 (2009) 590–594.
- [252] M.M. Ren, Z. Zhou, L.W. Su, X.P. Gao, LiVPO<sub>4</sub>: a cathode material for 4V lithium ion batteries, *J. Power Sources* 189 (2009) 786–789.
- [253] R.K. Katiyar, R. Singhal, K. Asmar, R. Valentin, R.S. Katiyar, High voltage spinel cathode materials for high energy density and high rate capability Li ion rechargeable batteries, *J. Power Sources* 194 (2009) 526–530.
- [254] M. Akalouch, J.M. Amarilla, R.M. Rojas, I. Saadoun, J.M. Rojo, Chromium doping as a new approach to improve the cycling performance at high temperature of 5V LiNi<sub>0.5</sub>Mn<sub>1.5</sub>O<sub>4</sub>-based positive electrode, *J. Power Sources* 185 (2008) 501–511.
- [255] T.-F. Yi, C.-Y. Li, Y.-R. Zhu, J. Shu, R.-S. Zhu, Comparison of structure and electrochemical properties for 5V LiNi<sub>0.5</sub>Mn<sub>1.5</sub>O<sub>4</sub> and LiNi<sub>0.4</sub>Cr<sub>0.2</sub>Mn<sub>1.4</sub>O<sub>4</sub> cathode materials, *J. Solid State Electrochem.* 13 (2009) 913–919.
- [256] Y. Kobayashi, Y. i Mita, S. Seki, Y. Ohno, H. Miyashiro, M. Nakayama, M. Wakihara, Configurational entropy of lithium manganese oxide and related



- materials,  $\text{LiCr}_y\text{Mn}_{2-y}\text{O}_4$  ( $y=0, 0.3$ ), *J. Electrochem. Soc.* 155 (1) (2008) A14–A19.
- [257] C.P. Grey, N. Dupré, NMR studies of cathode materials for lithium-ion rechargeable batteries, *Chem. Rev.* 104 (2004) 4493–4512.
- [258] N.K. Karan, M. Balasubramanian, D.P. Abraham, M.M. Furczon, D.K. Pradhan, J.J. Saavedra-Arias, R. Thomas, R.S. Katiyar, Structural characteristics and electrochemical performance of layered  $\text{Li}[\text{Mn}_{0.5-x}\text{Cr}_{2x}\text{Ni}_{0.5-x}]\text{O}_2$  cathode materials, *J. Power Sources* 187 (2009) 586–590.
- [259] N.K. Karan, D.P. Abraham, M. Balasubramanian, M.M. Furczon, R. Thomas, R.S. Katiyar, Morphology, structure, and electrochemistry of solution-derived  $\text{LiMn}_{0.5-x}\text{Cr}_{2x}\text{Ni}_{0.5-x}\text{O}_2$  for lithium-ion cells, *J. Electrochem. Soc.* 156(7) (2009) A553–A562.
- [260] L. Liu, K. Sun, N. Zhang, T. Yang, Improvement of high-voltage cycling behavior of  $\text{Li}(\text{Ni}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3})\text{O}_2$  cathodes by Mg, Cr, and Al substitution, *J. Solid State Electrochem.* 13 (2009) 1381–1386.
- [261] S.Y. Zhan, C.Z. Wang, K. Nikolowski, H. Ehrenberg, G. Chen, Y.J. Wei, Electrochemical properties of Cr doped  $\text{V}_2\text{O}_5$  between 3.8V and 2.0V, *Solid State Ionics* 180 (2009) 1198–1203.
- [262] Y. Chen, Y. Zhao, X. An, J. Liu, Y. Dong, L. Chen, Preparation and electrochemical performance studies on Cr-doped  $\text{Li}_3\text{V}_2(\text{PO}_4)_3$  as cathode materials for lithium-ion batteries, *Electrochim. Acta* 54 (2009) 5844–5850.
- [263] Y. Chen, R. Chen, Z. Tang, L. Wang, Synthesis and characterization of Zn-doped  $\text{LiCo}_{0.3}\text{Ni}_{0.4-x}\text{Mn}_{0.3}\text{Zn}_x\text{O}_2$  cathode materials for lithium-ion batteries, *J. Alloys Compd.* 476 (2009) 539–542.
- [264] A.Y. Shenouda, H.K. Liu, Studies on electrochemical behaviour of zinc-doped  $\text{LiFePO}_4$  for lithium battery positive electrode, *J. Alloys Compd.* 477 (2009) 498–503.
- [265] N. Kitamura, H. Iwatsuki, Y. Idemoto, Improvement of cathode performance of  $\text{LiMn}_2\text{O}_4$  as a cathode active material for Li ion battery by step-by-step supersonic-wave, *J. Power Sources* 189 (2009) 114–120.
- [266] R. Guo, P. Shi, X. Cheng, L. Sun, Effect of ZnO modification on the performance of  $\text{LiNi}_{0.5}\text{Co}_{0.25}\text{Mn}_{0.25}\text{O}_2$  cathode material, *Electrochim. Acta* 54 (2009) 5796–5803.
- [267] J. Liu, A. Manthiram, Improved electrochemical performance of the 5 V spinel cathode  $\text{LiMn}_{1.5}\text{Ni}_{0.42}\text{Zn}_{0.08}\text{O}_4$  by surface modification, *J. Electrochem. Soc.* 156 (1) (2009) A66–A72.
- [268] R. Singhal, M.S. Tomar, J.G. Burgo, R.S. Katiyar, Electrochemical performance of ZnO-coated  $\text{LiMn}_{1.5}\text{Ni}_{0.5}\text{O}_4$  cathode material, *J. Power Sources* 183 (2008) 334–338.
- [269] B. León, C.P. Vicente, J.L. Tirado, Ph. Biensan, C. Tessier, Optimized chemical stability and electrochemical performance of  $\text{LiFePO}_4$  composite materials obtained by ZnO coating, *J. Electrochem. Soc.* 155 (3) (2008) A211–A216.
- [270] X. Li, Y. Xu, Enhanced cycling performance of spinel  $\text{LiMn}_2\text{O}_4$  coated with  $\text{ZnMn}_2\text{O}_4$  shell, *J. Solid State Electrochem.* 12 (2008) 851–855.
- [271] J. Eom, J. Cho,  $\text{M}_3(\text{PO}_4)_2$ -nanoparticle-coated  $\text{LiCoO}_2$  vs  $\text{LiCo}_{0.96}\text{M}_{0.04}\text{O}_2$  ( $M=\text{Mg}$  and  $\text{Zn}$ ) on electrochemical and storage characteristics, *J. Electrochem. Soc.* 155 (3) (2008) A201–A205.
- [272] H. Tang, F. Zhao, Z.-R. Chang, X.-Z. Yuan, H. Wang, Synthesis and electrochemical properties of high density  $\text{LiNi}_{0.8}\text{Co}_{0.2-x}\text{Ti}_x\text{O}_2$  for lithium-ion batteries, *J. Electrochem. Soc.* 156 (6) (2009) A478–A482.
- [273] M.Y. Song, S.N. Kwon, S.-D. Yoon, D.R. Mumm, Electrochemical properties of  $\text{LiNi}_{1-y}\text{M}_y\text{O}_2$  ( $M=\text{Ni}$ ,  $\text{Ga}$ ,  $\text{Al}$  and/or  $\text{Ti}$ ) cathodes synthesized by the combustion method, *J. Appl. Electrochem.* 39 (2009) 807–814.
- [274] J. Saint, A.S. Best, A.F. Hollenkamp, J. Kerr, J.-H. Shin, M.M. Doeff, Compatibility of  $\text{Li}_x\text{Ti}_y\text{Mn}_{1-y}\text{O}_2$  ( $y=0, 0.11$ ) electrode materials with pyrrolidinium-based ionic liquid electrolyte systems, *J. Electrochem. Soc.* 155 (2) (2008) A172–A180.
- [275] J.A. Saint, M.M. Doeff, J. Wilcox, Electrode materials with the  $\text{Na}_{0.44}\text{MnO}_2$  structure: Effect of titanium substitution on physical and electrochemical properties, *Chem. Mater.* 20 (10) (2008) 3404–3411.
- [276] L.J. Hardwick, J.A. Saint, I.T. Lucas, M.M. Doeff, R. Kosteckia, FTIR and Raman study of the  $\text{Li}_x\text{Ti}_y\text{Mn}_{1-y}\text{O}_2$  ( $y=0, 0.11$ ) cathodes in methylpropyl pyrrolidinium bis(fluoro-sulfonyl)imide, LiTFSI electrolyte, *J. Electrochem. Soc.* 156 (2) (2009) A120–A127.
- [277] G.Q. Liu, W.S. Yuan, G.Y. Liu, Y.W. Tian, The electrochemical properties of  $\text{LiNi}_{0.5}\text{Mn}_{1.2}\text{Ti}_{0.3}\text{O}_4$  compound, *J. Alloys Compd.*, in press, doi:10.1016/j.jallcom.2009.04.141.
- [278] S.-H. Wu, M.-S. Chen, C.-J. Chien, Y.-P. Fu, Preparation and characterization of  $\text{Ti}^{4+}$ -doped  $\text{LiFePO}_4$  cathode materials for lithium-ion batteries, *J. Power Sources* 189 (2009) 440–444.
- [279] L. Wu, X.-H. Li, Z.-X. Wang, L.-J. Li, J.-C. Zheng, H.-J. Guo, Q.-Y. Hu, J. Fang, Synthesis and electrochemical properties of metals-doped  $\text{LiFePO}_4$  prepared from the  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$  waste slag, *J. Power Sources* 189 (2009) 681–684.
- [280] J.M. Zheng, J. Li, Z.R. Zhang, X.J. Guo, Y. Yang, The effects of  $\text{TiO}_2$  coating on the electrochemical performance of  $\text{Li}[\text{Li}_{0.2}\text{Mn}_{0.54}\text{Ni}_{0.13}\text{Co}_{0.13}]\text{O}_2$  cathode material for lithium-ion battery, *Solid State Ionics* 179 (2008) 1794–1799.
- [281] S. Sivaprakash, S.B. Majumder, Understanding the role of  $\text{Zr}^{4+}$  cation in improving the cycleability of  $\text{LiNi}_{0.8}\text{Co}_{0.15}\text{Zr}_{0.05}\text{O}_2$  cathodes for Li ion rechargeable batteries, *J. Alloys Compd.* 479 (2009) 561–568.
- [282] H. Liu, C. Li, Q. Cao, Y.P. Wu, R. Holze, Effects of heteroatoms on doped  $\text{LiFePO}_4/\text{C}$  composites, *J. Solid State Electrochem.* 12 (2008) 1017–1020.
- [283] N. Meethong, Y.-H. Kao, S.A. Speakman, Y.-M. Chiang, Alivalent substitutions in olivine lithium iron phosphate and impact on structure and properties, *Adv. Funct. Mater.* 19 (2009) 1060–1070.
- [284] M. Wagemaker, B.L. Ellis, D. Lützenkirchen-Hecht, F.M. Mulder, L.F. Nazar, Proof of supervalent doping in olivine  $\text{LiFePO}_4$ , *Chem. Mater.* 20 (22) (2008) 6313–6315.
- [285] G.-Y. Kim, Y.J. Park, K.H. Jung, D.-J. Yang, J.W. Lee, H.G. Kim, High-rate, high capacity  $\text{ZrO}_2$  coated  $\text{Li}[\text{Li}_{1/6}\text{Mn}_{1/2}\text{Co}_{1/6}\text{Ni}_{1/6}]\text{O}_2$  for lithium secondary batteries, *J. Appl. Electrochem.* 38 (2008) 1477–1481.
- [286] S.B. Park, H.C. Shin, W.-G. Lee, W.I. Cho, H. Jang, Improvement of capacity fading resistance of  $\text{LiMn}_2\text{O}_4$  by amphoteric oxides, *J. Power Sources* 180 (2008) 597–601.
- [287] T. Doi, J.-I. Kageura, S. Okada, J.I. Yamaki, Surface modification of  $\text{LiNi}_{1/2}\text{Mn}_{3/2}\text{O}_4$  thin-films by zirconium alkoxide/PMMA composites and their effects on electrochemical properties, *J. Power Sources* 185 (2008) 473–479.
- [288] W. Luo, J.R. Dahn, Comparative study of  $\text{Li}[\text{Co}_{1-x}\text{Al}_x]\text{O}_2$  prepared by solid state and coprecipitation methods, *Electrochim. Acta* 54 (2009) 4655–4661.
- [289] B. Zhang, G. Chen, P. Xu, C.C. Li, Effect of equivalent and non-equivalent Al substitutions on the structure and electrochemical properties of  $\text{LiNi}_{0.5}\text{Mn}_{0.5}\text{O}_2$ , *J. Power Sources* 176 (2008) 325–331.
- [290] S. Komaba, K. Yoshii, A. Ogata, I. Nakai, Structural, electrochemical behaviors of metastable  $\text{Li}_{2/3}[\text{Ni}_{1/3}\text{Mn}_{2/3}]\text{O}_2$  modified by metal element substitution, *Electrochim. Acta* 54 (2009) 2353–2359.
- [291] B. Zhang, G. Chen, Y. Liang, P. Xu, Structural and electrochemical properties of  $\text{LiNi}_{0.5}\text{Mn}_{0.5-x}\text{Al}_x\text{O}_2$  ( $x=0, 0.02, 0.05, 0.08, \text{ and } 0.1$ ) cathode materials for lithium-ion batteries, *Solid State Ionics* 180 (2009) 398–404.
- [292] F. Zhou, X. Zhao, Z. Lu, J. Jiang, J.R. Dahn, The effect of Al substitution on the reactivity of delithiated  $\text{LiNi}_{(0.5-2)}\text{Mn}_{(0.5-2)}\text{Al}_{2z}\text{O}_2$  with nonaqueous electrolyte, *Electrochem. Solid-State Lett.* 11 (9) (2008) A155–A157.
- [293] Y.-K. Lin, C.-H. Lu, Preparation and electrochemical properties of layer-structured  $\text{LiNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3-y}\text{Al}_y\text{O}_2$ , *J. Power Sources* 189 (2009) 353–358.
- [294] F. Zhou, X. Zhao, J.R. Dahn, Synthesis, electrochemical properties, and thermal stability of Al-doped  $\text{LiNi}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3-2z}\text{Al}_z\text{O}_2$  positive electrode materials, *J. Electrochem. Soc.* 156 (4) (2009) A343–A347.
- [295] F. Zhou, X. Zhao, J. Jiang, J.R. Dahn, Advantages of simultaneous substitution of Co in  $\text{Li}[\text{Ni}_{1/3}\text{Mn}_{1/3}\text{Co}_{1/3}]\text{O}_2$  by Ni and Al, *Electrochem. Solid-State Lett.* 12 (4) (2009) A81–A83.
- [296] J.D. Wilcox, M.M. Doeff, Characterization and electrochemical performance of substituted  $\text{LiNi}_{0.4}\text{Co}_{0.2-y}\text{Al}_y\text{Mn}_{0.4}\text{O}_2$  ( $0 \leq y \leq 0.2$ ) cathode materials, *ECS Trans.* 11 (29) (2008) 27–33.
- [297] S.-W. Woo, S.-T. Myung, H. Bang, D.-W. Kim, Y.-K. Sun, Improvement of electrochemical and thermal properties of  $\text{Li}[\text{Ni}_{0.8}\text{Co}_{0.1}\text{Mn}_{0.1}]\text{O}_2$  positive electrode materials by multiple metal (Al, Mg) substitution, *Electrochim. Acta* 54 (2009) 3851–3856.
- [298] L. Xiao, Y. Zhao, Y. Yang, Y. Cao, X. Ai, H. Yang, Enhanced electrochemical stability of Al-doped  $\text{LiMn}_2\text{O}_4$  synthesized by a polymer-pyrolysis method, *Electrochim. Acta* 54 (2008) 545–550.
- [299] W. Luo, J.R. Dahn, Preparation of  $\text{Co}_{1-z}\text{Al}_z(\text{OH})_2(\text{NO}_3)_z$  layered double hydroxides and  $\text{Li}(\text{Co}_{1-z}\text{Al}_z)\text{O}_2$ , *Chem. Mater.* 21 (1) (2009) 56–62.
- [300] T. Sasaki, T. Nonaka, H. Oka, C. Okuda, Y. Itou, Y. Kondo, Y. Takeuchi, Y. Ukyo, K. Tatsumi, S. Muto, Capacity-fading mechanisms of  $\text{LiNiO}_2$ -based lithium-ion batteries. I. Analysis by electrochemical and spectroscopic examination, *J. Electrochem. Soc.* 156 (4) (2009) A289–A293.
- [301] S. Muto, Y. Sasano, K. Tatsumi, T. Sasaki, K. Horibuchi, Y. Takeuchi, Y. Ukyo, Capacity-fading mechanisms of  $\text{LiNiO}_2$ -based lithium-ion batteries. II. Diagnostic analysis by electron microscopy and spectroscopy, *J. Electrochem. Soc.* 156 (5) (2009) A371–A377.
- [302] J. Shim, R. Kostecki, T. Richardson, X. Song, K.A. Striebel, Electrochemical analysis for cycle performance and capacity fading of a lithium-ion battery cycled at elevated temperature, *J. Power Sources* 112 (2002) 222–230.
- [303] K. Shizuka, C. Kiyohara, K. Shima, K. Okahara, K. Okamoto, Y. Takeda, Effect of  $\text{CO}_2$  on layered  $\text{Li}_{1+z}\text{M}_{1-x-y}\text{Co}_y\text{M}_y\text{O}_2$  ( $M=\text{Al}, \text{Mn}$ ) cathode materials, *ECS Trans.* 11 (29) (2008) 7–13.
- [304] N. Kosova, E. Devyatkina, A. Slobodyuk, V. Kaichev, Surface chemistry study of  $\text{LiCoO}_2$  coated with alumina, *Solid State Ionics* 179 (2008) 1745–1749.
- [305] Y. Bai, Y. Yin, N. Liu, B. Guo, H. Shi, J. Liu, Z. Wang, L. Chen, New concept of surface modification to  $\text{LiCoO}_2$ , *J. Power Sources* 174 (2007) 328–334.
- [306] J. Xiang, C. Chang, L. Yuan, J. Sun, A simple and effective strategy to synthesize  $\text{Al}_2\text{O}_3$ -coated  $\text{LiNi}_{0.8}\text{Co}_{0.2}\text{O}_2$  cathode materials for lithium ion battery, *Electrochem. Commun.* 10 (2008) 1360–1363.
- [307] G.T.-K. Fey, C.-S. Chang, T.P. Kumar, Synthesis and surface treatment of  $\text{LiNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}\text{O}_2$  cathode materials for Li-ion batteries, *J. Solid State Electrochem.*, in press, doi:10.1007/s10008-008-0772-3.
- [308] H. Lee, H.-J. Kim, D. Kim, S. Choi, Expanding performance limit of lithium-ion batteries simply by mixing  $\text{Al}(\text{OH})_3$  powder with  $\text{LiCoO}_2$ , *J. Power Sources* 176 (2008) 359–362.
- [309] Z. Yang, W. Yang, D.G. Evans, Y. Zhao, X. Wei, The effect of a Co–Al mixed metal oxide coating on the elevated temperature performance of a  $\text{LiMn}_2\text{O}_4$  cathode material, *J. Power Sources* 189 (2009) 1147–1153.
- [310] J.-M. Chen, Y.-D. Cho, C.-L. Hsiao, G.T.-K. Fey, Electrochemical studies on  $\text{LiCoO}_2$  surface coated with  $\text{Y}_3\text{Al}_5\text{O}_{12}$  for lithium-ion cells, *J. Power Sources* 189 (2009) 279–287.
- [311] C.-Z. Lu, J.-M. Chen, Y.-D. Cho, W.-H. Hsu, P. Muralidharana, G.T.-K. Fey, Electrochemical performance of  $\text{LiCoO}_2$  cathodes by surface modification using lanthanum aluminum garnet, *J. Power Sources* 184 (2008) 392–401.
- [312] Y.-K. Sun, S.-T. Myung, B.-C. Park, H. Yashiro, Improvement of the electrochemical properties of  $\text{Li}[\text{Ni}_{0.5}\text{Mn}_{0.5}]\text{O}_2$  by  $\text{AlF}_3$  coating, *J. Electrochem. Soc.* 155 (10) (2008) A705–A710.

- [313] J.M. Zheng, Z.R. Zhang, X.B. Wu, Z.X. Dong, Z. Zhu, Y. Yang, The effects of  $\text{AlF}_3$  coating on the performance of  $\text{Li}[\text{Li}_{0.2}\text{Mn}_{0.54}\text{Ni}_{0.13}\text{Co}_{0.13}]\text{O}_2$  positive electrode material for lithium-ion battery, *J. Electrochem. Soc.* 155 (10) (2008) A775–A782.
- [314] H.-B. Kim, B.-C. Park, S.-T. Myung, K. Amine, J. Prakash, Y.-K. Sun, Electrochemical and thermal characterization of  $\text{AlF}_3$ -coated  $\text{Li}[\text{Ni}_{0.8}\text{Co}_{0.15}\text{Al}_{0.05}]\text{O}_2$  cathode in lithium-ion cells, *J. Power Sources* 179 (2008) 347–350.
- [315] G.G. Amatucci, N. Pereira, Fluoride based electrode materials for advanced energy storage devices, *J. Fluorine Chem.* 128 (2007) 243–262.
- [316] Y. Wu, A.V. Murugan, A. Manthiram, Surface modification of high capacity layered  $\text{Li}[\text{Li}_{0.2}\text{Mn}_{0.54}\text{Ni}_{0.13}\text{Co}_{0.13}]\text{O}_2$  cathodes by  $\text{AlPO}_4$ , *J. Electrochem. Soc.* 155 (9) (2008) A635–A641.
- [317] Y. Zeng, J. He, Surface structure investigation of  $\text{LiNi}_{0.8}\text{Co}_{0.2}\text{O}_2$  by  $\text{AlPO}_4$  coating and using functional electrolyte, *J. Power Sources* 189 (2009) 519–521.
- [318] Y. Kim, Y. Hong, K.S. Ryu, M.G. Kim, J. Cho, Structural changes of bare and  $\text{AlPO}_4$ -coated  $\text{Li}_x\text{CoO}_2$  ( $x = 0.24$  and  $0.1$ ) upon thermal annealing  $\geq 200^\circ\text{C}$ , *J. Power Sources* 179 (2008) 780–784.
- [319] Y.-K. Sun, S.-T. Myung, C.S. Yoon, D.-W. Kim, Improvement of high voltage cycling performances of  $\text{Li}[\text{Ni}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}]\text{O}_2$  at  $55^\circ\text{C}$  by a  $(\text{NH}_4)_3\text{AlF}_6$  coating, *Electrochem. Solid-State Lett.* 12 (8) (2009) A163–A166.
- [320] D. Arumugam, G.P. Kalaignan, P. Manisankar, Synthesis and electrochemical characterizations of nano-crystalline  $\text{LiFePO}_4$  and Mg-doped  $\text{LiFePO}_4$  cathode materials for rechargeable lithium-ion batteries, *J. Solid State Electrochem.* 13 (2009) 301–307.
- [321] X. Ou, G. Liang, L. Wang, S. Xu, X. Zhao, Effects of magnesium doping on electronic conductivity and electrochemical properties of  $\text{LiFePO}_4$  prepared via hydrothermal route, *J. Power Sources* 184 (2008) 543–547.
- [322] C.N. Zaheena, C. Nithya, R. Thirunakaran, A. Sivashanmugam, S. Gopukumar, Microwave assisted synthesis, electrochemical behaviour of  $\text{LiMg}_{0.1}\text{Co}_{0.9}\text{O}_2$  for lithium rechargeable batteries, *Electrochim. Acta* 54 (2009) 2877–2882.
- [323] J. Xiang, C. Chang, F. Zhang, J. Sun, Effects of Mg doping on the electrochemical properties of  $\text{LiNi}_{0.8}\text{Co}_{0.2}\text{O}_2$  cathode material, *J. Alloys Compounds* 475 (2009) 483–487.
- [324] J. Xiang, C. Chang, F. Zhang, J. Sun, Rheological phase synthesis and electrochemical properties of Mg-doped  $\text{LiNi}_{0.8}\text{Co}_{0.2}\text{O}_2$  cathode materials for lithium-ion battery, *J. Electrochem. Soc.* 155 (7) (2008) A520–A525.
- [325] Y. Gu, D. Chen, X. Jiao, F. Liu,  $\text{LiCoO}_2$ -MgO coaxial fibers: co-electrospun fabrication, characterization and electrochemical properties, *J. Mater. Chem.* 17 (2007) 1767–1776.
- [326] Z. Yang, W. Yang, Z. Tang, Pillared layered  $\text{Li}_{1-2x}\text{Ca}_x\text{CoO}_2$  cathode materials obtained by cationic exchange under hydrothermal conditions, *J. Power Sources* 184 (2008) 561–577.
- [327] Y.-D. Cho, G.T.-K. Fey, H.-M. Kao, Physical and electrochemical properties of La-doped  $\text{LiFePO}_4/\text{C}$  composites as cathode materials for lithium-ion batteries, *J. Solid State Electrochem.* 12 (2008) 815–823.
- [328] D. Li, Y. Huang, D. Jia, Z. Guo, S.-J. Bao, Synthesis and electrochemical properties of nanosized carbon-coated  $\text{Li}_{1-3x}\text{La}_x\text{FePO}_4$  composites, *J. Solid State Electrochem.*, in press, doi:10.1007/s10008-009-0875-5.
- [329] P. Ghosh, S. Mahanty, R.N. Basu, Lanthanum-doped  $\text{LiCoO}_2$  cathode with high rate capability, *Electrochim. Acta* 54 (2009) 1654–1661.
- [330] Y. Liu, C. Mi, C. Yuan, X. Zhang, Improvement of electrochemical and thermal stability of  $\text{LiFePO}_4$  cathode modified by  $\text{CeO}_2$ , *J. Electroanal. Chem.* 628 (2009) 73–80.
- [331] A. Sakuda, H. Kitaura, A. Hayashi, K. Tadanaga, M. Tatsumisago, Modification of interface between  $\text{LiCoO}_2$  electrode and  $\text{Li}_2\text{S}-\text{P}_2\text{S}_5$  solid electrolyte using  $\text{Li}_2\text{O}-\text{SiO}_2$  glassy layers, *J. Electrochem. Soc.* 156 (1) (2009) A27–A32.
- [332] A. Sakuda, H. Kitaura, A. Hayashi, K. Tadanaga, M. Tatsumisago, Improvement of high-rate performance of all-solid-state lithium secondary batteries using  $\text{LiCoO}_2$  coated with  $\text{Li}_2\text{O}-\text{SiO}_2$  glasses, *Electrochem. Solid-State Lett.* 11 (1) (2008) A1–A3.
- [333] A. Sakuda, H. Kitaura, A. Hayashi, K. Tadanaga, M. Tatsumisago, All-solid-state lithium secondary batteries with oxide-coated  $\text{LiCoO}_2$  electrode,  $\text{Li}_2\text{S}-\text{P}_2\text{S}_5$  electrolyte, *J. Power Sources* 189 (2009) 530–527.
- [334] F. Wu, M. Wang, Y. Su, S. Chen, Surface modification of  $\text{LiCo}_{1/3}\text{Ni}_{1/3}\text{Mn}_{1/3}\text{O}_2$  with  $\text{Y}_2\text{O}_3$  for lithium-ion battery, *J. Power Sources* 189 (2009) 743–747.
- [335] D. Arumugam, G.P. Kalaignan, Synthesis and electrochemical characterizations of Nano- $\text{SiO}_2$ -coated  $\text{LiMn}_2\text{O}_4$  cathode materials for rechargeable lithium batteries, *J. Electroanal. Chem.* 624 (2008) 197–204.
- [336] J.-P. Yu, X.-H. Hu, H. Zhan, Y.-H. Zhou,  $\text{Sb}_2\text{O}_3$ -modified  $\text{Li}_{1-x}\text{Co}_x\text{O}_2$  phase as cathode material for lithium ion battery, *J. Power Sources* 189 (2009) 697–701.
- [337] C.L. Tan, H.J. Zhou, W.S. Li, X.H. Hou, D.S. Lü, M.Q. Xu, Q.M. Huang, Performance improvement of  $\text{LiMn}_2\text{O}_4$  as cathode material for lithium ion battery with bismuth modification, *J. Power Sources* 184 (2008) 408–413.
- [338] S. Guo, S. Zhang, X. He, W. Pu, C. Jiang, C. Wan, Synthesis and characterization of Sn-doped  $\text{LiMn}_2\text{O}_4$  cathode materials for rechargeable Li-ion batteries, *J. Electrochem. Soc.* 155 (10) (2008) A760–A763.
- [339] D.-G. Tong, Y.-Y. Luo, W. Chu, Y. He, X.-Y. Ji, Synthesis and characterization of  $\text{LiCo}_{0.3}\text{Rh}_x\text{Ni}_{0.7-x}\text{O}_2$  ( $0 \leq x \leq 0.003$ ) cathode materials for lithium ion batteries, *Mater. Chem. Phys.* 105 (2007) 47–52.
- [340] Z. Su, Z.W. Lu, X.P. Gao, P.W. Shen, X.J. Liu, J.Q. Wang, Preparation and electrochemical properties of indium- and sulfur-doped  $\text{LiMnO}_2$  with orthorhombic structure as cathode materials, *J. Power Sources* 189 (2009) 411–414.
- [341] T. Nakajima, Surface modification of carbon anodes for secondary lithium battery by fluorination, *J. Fluorine Chem.* 128 (2007) 277–284.
- [342] N. Pereira, F. Badway, M. Wartelsky, S. Gunn, G.G. Amatucci, Iron oxyfluorides as high capacity cathode materials for lithium batteries, *J. Electrochem. Soc.* 156 (6) (2009) A407–A416.
- [343] I.D. Gocheva, I. Tanaka, T. Doi, S. Okada, J.-I. Yamaki, A new iron oxyfluoride cathode active material for Li-ion battery,  $\text{Fe}_2\text{OF}_4$ , *Electrochem. Commun.* 11 (2009) 1583–1585.
- [344] G. Du, Y. NuLi, J. Yang, Fluorine-doped  $\text{LiNi}_{0.5}\text{Mn}_{1.5}\text{O}_4$  for 5 V cathode materials of lithium-ion battery, *Mater. Res. Bull.* 43 (2008) 3607–3613.
- [345] K. Matsumoto, T. Fukutsuka, T. Okumura, Y. Uchimoto, K. Amezawa, M. Inaba, A. Tasaka, Electronic structures of partially fluorinated lithium manganese spinel oxides and their electrochemical properties, *J. Power Sources* 189 (2009) 599–601.
- [346] Y.-S. He, L. Pei, X.-Z. Liao, Z.-F. Ma, Synthesis of  $\text{LiNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}\text{O}_{2-z}\text{F}_z$  cathode material from oxalate precursors for lithium ion battery, *J. Fluorine Chem.* 128 (2007) 139–143.
- [347] L. Croguennec, J. Bains, M. Ménétrier, A. Flambard, E. Bekaert, C. Jordy, P. Bien-san, C. Delmas, Synthesis of “ $\text{Li}_{1.1}(\text{Ni}_{0.425}\text{Mn}_{0.425}\text{Co}_{0.15})_{0.9}\text{O}_{1.8}\text{F}_{0.2}$ ” materials by different routes: Is there fluorine substitution for oxygen? *J. Electrochem. Soc.* 156 (5) (2009) A349–A355.
- [348] J. Li, L. Wang, Q. Zhang, X. He, Electrochemical performance of  $\text{SrF}_2$ -coated  $\text{LiNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}\text{O}_2$  cathode materials for Li-ion batteries, *J. Power Sources* 190 (2009) 149–153.
- [349] J. Morales, R. Trócoli, E. Rodríguez-Castellón, S. Franger, J. Santos-Peña, Effect of C and Au additives produced by simple coatings on the surface and the electrochemical properties of nanosized  $\text{LiFePO}_4$ , *J. Electroanal. Chem.* 631 (2009) 29–35.
- [350] P. Ghosh, S. Mahanty, R.N. Basu, Effect of silver addition on the properties of combustion synthesized nanocrystalline  $\text{LiCoO}_2$ , *Mater. Chem. Phys.* 110 (2008) 406–410.
- [351] R. Guo, P. Shi, X. Cheng, Y. Ma, Z. Tan, Effect of Ag additive on the performance of  $\text{LiNi}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}\text{O}_2$  cathode material for lithium ion battery, *J. Power Sources* 189 (2009) 2–8.
- [352] B. Lin, Z. Wen, J. Han, X. Wu, Electrochemical properties of carbon-coated  $\text{Li}[\text{Ni}_{1/3}\text{Co}_{1/3}\text{Mn}_{1/3}]\text{O}_2$  cathode material for lithium-ion batteries, *Solid State Ionics* 179 (2008) 1750–1753.
- [353] T.J. Patey, R. Büchel, S.H. Ng, F. Krumeich, S.E. Pratsinis, P. Novák, Flame co-synthesis of  $\text{LiMn}_2\text{O}_4$  and carbon nanocomposites for high power batteries, *J. Power Sources* 189 (2009) 149–154.
- [354] N.M. Hagh, G.G. Amatucci, Electrochemical performance of nanostructured  $\text{LiMn}_{1.5}\text{Ni}_{0.5}\text{O}_4$  spinel at elevated temperature, *ECS Trans.* 11 (29) (2008) 21–26.
- [355] C.-Z. Lu, G.T.-K. Fey, H.-M. Kao, Study of  $\text{LiFePO}_4$  cathode materials coated with high surface area carbon, *J. Power Sources* 189 (2009) 155–162.
- [356] J.L. Jones, J.-T. Hung, Y.S. Meng, Intermittent X-ray diffraction study of kinetics of delithiation in nano-scale  $\text{LiFePO}_4$ , *J. Power Sources* 189 (2009) 702–705.
- [357] H. Joachin, T.D. Kaun, K. Zaghbi, J. Prakash, Electrochemical and thermal studies of carbon-coated  $\text{LiFePO}_4$  cathode, *J. Electrochem. Soc.* 156 (6) (2009) A401–A406.
- [358] Y.-D. Cho, G.T.-K. Fey, H.-M. Kao, The effect of carbon coating thickness on the capacity of  $\text{LiFePO}_4/\text{C}$  composite cathodes, *J. Power Sources* 189 (2009) 256–262.
- [359] H.H. Li, J. Jin, J.P. Wei, Z. Zhou, J. Yan, Fast synthesis of core-shell  $\text{LiCoPO}_4/\text{C}$  nanocomposite via microwave heating and its electrochemical Li intercalation performances, *Electrochem. Commun.* 11 (2009) 95–98.
- [360] E.M. Jin, B. Jin, D.-K. Jun, K.-H. Park, H.-B. Gu, K.-W. Kim, A study on the electrochemical characteristics of  $\text{LiFePO}_4$  cathode for lithium polymer batteries by hydrothermal method, *J. Power Sources* 178 (2008) 801–806.
- [361] Y.L. Cao, L.H. Yu, T. Li, X.P. Ai, H.X. Yang, Synthesis and electrochemical characterization of carbon-coated nanocrystalline  $\text{LiFePO}_4$  prepared by polyacrylates-pyrolysis route, *J. Power Sources* 172 (2007) 913–918.
- [362] H.-P. Liu, Z.-C. Wang, X.-H. Li, H.-J. Guo, W.-J. Peng, Y.-H. Zhang, Q.-Y. Hu, Synthesis and electrochemical properties of olivine  $\text{LiFePO}_4$  prepared by a carbothermal reduction method, *J. Power Sources* 184 (2008) 469–472.
- [363] L. Zhang, X. Lv, Y. Wen, F. Wang, H. Su, Carbon combustion synthesis of  $\text{LiNi}_{0.5}\text{Mn}_{1.5}\text{O}_4$  and its use as a cathode material for lithium ion batteries, *J. Alloys Compd.* 480 (2009) 802–805.
- [364] A.P. Tang, X.Y. Wang, S.Y. Yang, J.Q. Cao, Synthesis and electrochemical properties of monoclinic  $\text{Li}_3\text{V}_2(\text{PO}_4)_3/\text{C}$  composite cathode material prepared from a sucrose-containing precursor, *J. Appl. Electrochem.* 38 (2008) 1453–1457.
- [365] X. Yan, G. Yang, J. Liu, Y. Ge, H. Xie, X. Pan, R. Wang, An effective and simple way to synthesize  $\text{LiFePO}_4/\text{C}$  composite, *Electrochim. Acta* 54 (2009) 5770–5774.
- [366] B. Jin, E.M. Jin, K.-H. Park, H.-B. Gu, Electrochemical properties of  $\text{LiFePO}_4$ -multiwalled carbon nanotubes composite cathode materials for lithium polymer battery, *Electrochem. Commun.* 10 (2008) 1537–1540.
- [367] B. Jin, H.-B. Gu, W. Zhang, K.-H. Park, G. Sun, Effect of different carbon conductive additives on electrochemical properties of  $\text{LiFePO}_4/\text{C}/\text{Li}$  batteries, *J. Solid State Electrochem.* 12 (2008) 1549–1554.
- [368] M.S. Bhuvanawari, N.N. Bramnik, D. Enslin, H. Ehrenberg, W. Jaegermann, Synthesis and characterization of carbon nano fiber/ $\text{LiFePO}_4$  composites for Li-ion batteries, *J. Power Sources* 180 (2008) 553–560.
- [369] Y. Liu, X. Li, H. Guo, Z. Wang, W. Peng, Y. Yang, R. Liang, Effect of carbon nanotube on the electrochemical performance of C- $\text{LiFePO}_4$ /graphite battery, *J. Power Sources* 184 (2008) 522–526.

- [370] D. Rangappa, M. Ichihara, T. Kudo, I. Honma, Surface modified LiFePO<sub>4</sub>/C nanocrystals synthesis by organic molecules assisted supercritical water process molecules assisted supercritical water process, *J. Power Sources* 194 (2009) 1036–1042.
- [371] B. Jin, H.-B. Gu, K.-W. Kim, Effect of different conductive additives on charge/discharge properties of LiCoPO<sub>4</sub>/Li batteries, *J. Solid State Electrochem.* 12 (2008) 105–111.
- [372] S.-B. Ma, K.-W. Nam, W.-S. Yoon, S.-M. Bak, X.-Q. Yang, B.-W. Cho, K.-B. Kim, Nano-sized lithium manganese oxide dispersed on carbon nanotubes for energy storage applications, *Electrochem. Commun.* 11 (2009) 1575–1578.
- [373] X.H. Rui, C. Li, C.H. Chen, Synthesis and characterization of carbon coated Li<sub>3</sub>V<sub>2</sub>(PO<sub>4</sub>)<sub>3</sub> cathode materials with different carbon sources, *Electrochim. Acta* 54 (2009) 3374–3380.
- [374] Z.-Y. Chen, H.-L. Zhu, S. Ji, R. Fakir, V. Linkov, Influence of carbon sources on electrochemical performances of LiFePO<sub>4</sub>/C composites, *Solid State Ionics* 179 (2008) 1810–1815.
- [375] G. Liang, L. Wang, X. Ou, X. Zhao, S. Xu, Lithium iron phosphate with high-rate capability synthesized through hydrothermal reaction in glucose solution, *J. Power Sources* 184 (2008) 538–542.
- [376] X. Zhou, Y. Liu, Y. Guo, Effect of reduction agent on the performance of Li<sub>3</sub>V<sub>2</sub>(PO<sub>4</sub>)<sub>3</sub>/C positive material by one-step solid state reaction, *Electrochim. Acta* 54 (2009) 2253–2258.
- [377] G.T.-K. Fey, T.-L. Lu, Morphological characterization of LiFePO<sub>4</sub>/C composite cathode materials synthesized via a carboxylic acid route, *J. Power Sources* 178 (2008) 807–814.
- [378] G.T.-K. Fey, T.-L. Lu, F.-Y. Wu, W.-H. Li, Carboxylic acid-assisted solid-state synthesis of LiFePO<sub>4</sub>/C composites and their electrochemical properties as cathode materials for lithium-ion batteries, *J. Solid State Electrochem.* 12 (2008) 825–833.
- [379] C. Sisbandini, D. Brandell, T. Gustafsson, J.O. Thomas, Effect of short-chain amine coatings on the performance of LiFePO<sub>4</sub> Li-ion battery cathodes, *Electrochem. Solid-State Lett.* 12 (5) (2009) A99–A101.
- [380] D. Jugović, M. Mitrić, N. Cvjetičanin, B. Jančar, S. Mentus, D. Uskoković, Synthesis and characterization of LiFePO<sub>4</sub>/C composite obtained by sonochemical method, *Solid State Ionics* 179 (2008) 415–419.
- [381] Z.P. Cai, Y. Liang, W.S. Li, L.D. Xing, Y.H. Liao, Preparation and performances of LiFePO<sub>4</sub> cathode in aqueous solvent with polyacrylic acid as a binder, *J. Power Sources* 189 (2009) 547–551.
- [382] L. Sun, R. Cui, A.F. Jalbout, M. Li, X. Pan, R. Wang, H. Xie, LiFePO<sub>4</sub> as an optimum power cell material, *J. Power Sources* 189 (2009) 522–526.
- [383] S.-Y. Chen, B. Gao, L.-H. Su, C.-H. Mi, X.-G. Zhang, Electrochemical properties of LiFePO<sub>4</sub>/C synthesized using polypyrrole as carbon source, *J. Solid State Electrochem.* 13 (2009) 1361–1366.
- [384] K.-S. Park, S.B. Schougaard, J.B. Goodenough, Conducting-polymer/iron-redox-couple composite cathodes for lithium secondary batteries, *Adv. Mater.* 19 (2007) 848–851.
- [385] Y.-H. Huang, J.B. Goodenough, High-rate LiFePO<sub>4</sub> lithium rechargeable battery promoted by electrochemically active polymers electrochemically active polymers, *Chem. Mater.* 20 (23) (2008) 7237–7241.
- [386] E. Pérez-Capde, Y. Mosqueda, R. Martínez, C.R. Milian, O. Sánchez, J.A. Varela, A. Hortencia, E. Souza, P. Arandad, E. Ruiz-Hitzky, Preparation, properties as positive electrodes of PANI-LiNi<sub>0.8</sub>Co<sub>0.2</sub>O<sub>2</sub> nanocomposites, *J. Mater. Chem.* 18 (2008) 3965–3971.
- [387] L. Xiao, Y. Yang, Y. Zhao, X. Ai, H. Yang, Y. Cao, Enhanced electrochemical performance of submicron LiCoO<sub>2</sub> synthesized by polymer pyrolysis method, *J. Solid State Electrochem.* 12 (2008) 149–153.
- [388] C.-H. Lu, T.-Y. Wu, H.-C. Wu, M.-H. Yang, Z.-Z. Guo, I. Taniguchi, Preparation and electrochemical characteristics of spherical spinel cathode powders via an ultrasonic spray pyrolysis process, *Mater. Chem. Phys.* 112 (2008) 115–119.
- [389] B.J. Hwang, Y.W. Wu, M. Venkateswarlu, M.Y. Cheng, R. Santhanam, Influence of synthesis conditions on electrochemical properties of high-voltage Li<sub>1.02</sub>Ni<sub>0.5</sub>Mn<sub>1.5</sub>O<sub>4</sub> spinel cathode material, *J. Power Sources* 193 (2009) 828–833.
- [390] S.W. Oh, H.J. Bang, S.-T. Myung, Y.C. Bae, S.-M. Lee, Y.-K. Sun, The effect of morphological properties on the electrochemical behavior of high tap density C-LiFePO<sub>4</sub> prepared via coprecipitation, *J. Electrochem. Soc.* 155 (6) (2008) A414–A420.
- [391] J. Sun, K. Tang, X. Yu, H. Li, X. Huang, Needle-like LiFePO<sub>4</sub> thin films prepared by an off-axis pulsed laser deposition technique, *Thin Solid Films* 517 (2009) 2618–2622.
- [392] K. Tang, J. Sun, X. Yu, H. Li, X. Huang, Electrochemical performance of LiFePO<sub>4</sub> thin films with different morphology and crystallinity, *Electrochim. Acta* 54 (2009) 6565–6569.
- [393] D. Wang, H. Buqa, M. Crouzet, G. Deghenghi, T. Drezen, I. Exnar, N.-H. Kwon, J.H. Miners, L. Poletto, M. Grätzel, High-performance, nano-structured LiMnPO<sub>4</sub> synthesized via a polyol method, *J. Power Sources* 189 (2009) 624–628.
- [394] K. Nakamura, H. Hirano, D. Nishioka, S. Endou, K. Itsuki, Y. Michihiro, T. Moriga, N. Kuwata, J. Kawamura, Ionic diffusion and structural changes in lithium compounds, *Solid State Ionics* 180 (2009) 621–625.
- [395] K. Nakamura, H. Hirano, D. Nishioka, Y. Michihiro, T. Moriga, Lithium ionic diffusion in lithium cobalt oxides prepared by mechanical milling, *Solid State Ionics* 179 (2008) 1806–1809.
- [396] M. Sathiya, A.S. Prakash, K. Ramesha, A.K. Shukla, Rapid synthetic routes to prepare LiCo<sub>1/3</sub>Ni<sub>1/3</sub>Mn<sub>1/3</sub>O<sub>2</sub> as a high voltage, high-capacity Li-ion battery cathode material, *Mater. Res. Bull.* 44 (2009) 1990–1994.
- [397] Z. Bakenov, M. Nakayama, M. Wakihara, I. Taniguchi, Lithium AlPO<sub>4</sub> composite polymer battery with nanostructured LiMn<sub>2</sub>O<sub>4</sub> cathode, *J. Solid State Electrochem.* 12 (2008) 295–302.
- [398] N. Kamarulzaman, R. Yusoff, N. Kamarudin, N.H. Shaari, N.A.A. Aziz, M.A. Bustam, N. Blagojevic, M. Elcombe, M. Blackford, M. Avdeev, A.K. Arof, Investigation of the cell parameters, microstructures and electrochemical behaviour of LiMn<sub>2</sub>O<sub>4</sub> normal and nano powders, *J. Power Sources* 188 (2009) 274–280.
- [399] G.T.-K. Fey, Y.G. Chen, Electrochemical properties of LiFePO<sub>4</sub> prepared via ball-milling, *J. Power Sources* 189 (2009) 169–178.
- [400] C. Benoit, S. Franger, Chemistry and electrochemistry of lithium iron phosphate, *J. Solid State Electrochem.* 12 (2008) 987–993.
- [401] M. Maccario, L. Croguennec, F. Weill, F. Le Cras, C. Delmas, C-containing LiFePO<sub>4</sub> materials—Part II: Electrochemical characterization, *Solid State Ionics* 179 (2008) 2383–2389.
- [402] B. Jin, H.-B. Gu, Preparation and characterization of LiFePO<sub>4</sub> cathode materials by hydrothermal method, *Solid State Ionics* 178 (2008) 1907–1914.
- [403] H. Xia, H. Wang, W. Xiao, L. Lu, M.O. Lai, Properties of LiNi<sub>1/3</sub>Co<sub>1/3</sub>Mn<sub>1/3</sub>O<sub>2</sub> cathode material synthesized by a modified Pechini method for high-power lithium-ion batteries, *J. Alloys Compd.* 480 (2009) 696–701.
- [404] M. Jo, Y.-S. Hong, J. Choo, J. Cho, Effect of LiCoO<sub>2</sub> cathode nanoparticle size on high rate performance for Li-ion batteries, *J. Electrochem. Soc.* 156 (6) (2009) A430–A434.
- [405] J.C. Arrebola, A. Caballero, L. Hernán, J. Morales, PMMA-assisted synthesis of Li<sub>1-x</sub>Ni<sub>0.5</sub>Mn<sub>1.5</sub>O<sub>4-δ</sub> for high-voltage lithium batteries with expanded rate capability at high cycling temperatures, *J. Power Sources* 180 (2008) 852–858.
- [406] T.J. Patey, R. Büchel, M. Nakayama, P. Novák, Electrochemistry of LiMn<sub>2</sub>O<sub>4</sub> nanoparticles made by flame spray pyrolysis, *Phys. Chem. Chem. Phys.* 11 (2009) 3756–3761.
- [407] K. Dokko, N. Nakata, K. Kanamura, High rate discharge capability of single particle electrode of LiCoO<sub>2</sub>, *J. Power Sources* 189 (2009) 783–785.
- [408] C. Arbizzani, S. Beninati, M. Mastragostino, A three-dimensional carbon-coated LiFePO<sub>4</sub> electrode for high-power applications, *J. Appl. Electrochem.*, in press, doi:10.1007/s10800-009-9956-5.
- [409] F. Jiao, J. Bao, A.H. Hill, P.G. Bruce, Synthesis of ordered mesoporous Li–Mn–O spinel as a positive electrode for rechargeable lithium batteries, *Angew. Chem.* 120 (2008) 1–7.
- [410] D. Tonti, M.J. Torralvo, E. Enciso, I. Sobrados, J. Sanz, Three-dimensionally ordered macroporous lithium manganese oxide for rechargeable lithium batteries, *Chem. Mater.* 20 (14) (2008) 4783–4790.
- [411] C.M. Doherty, R.A. Caruso, B.M. Smarsly, C.J. Drummond, Colloidal crystal templating to produce hierarchically porous LiFePO<sub>4</sub> electrode materials for high power lithium ion batteries, *Chem. Mater.* 21 (13) (2009) 2895–2903.
- [412] H. Zheng, G. Liu, X. Song, V. Battaglia, Li[Ni<sub>1/3</sub>Mn<sub>1/3</sub>Co<sub>1/3</sub>]O<sub>2</sub>-based electrodes for PHEV applications: an optimization, *ECS Trans.* 11 (32) (2008) 1–9.
- [413] S.W. Oh, S.-T. Myung, H.J. Bang, C.S. Yoon, K. Amine, Y.-K. Sun, Nanoporous structured LiFePO<sub>4</sub> with spherical microscale particle having high volumetric capacity for lithium batteries, *Electrochem. Solid-State Lett.* 12 (9) (2009) A181–A185.
- [414] H.-L. Zhu, Z.-Y. Chen, S. Ji, V. Linkov, Influence of different morphologies on electrochemical performance of spinel LiMn<sub>2</sub>O<sub>4</sub>, *Solid State Ionics* 179 (2008) 1788–1793.
- [415] S.H. Ju, Y.C. Kang, Fine-sized LiNi<sub>0.8</sub>Co<sub>0.15</sub>Mn<sub>0.05</sub>O<sub>2</sub> cathode powders prepared by combined process of gas-phase reaction and solid-state reaction methods, *J. Power Sources* 178 (2008) 387–392.
- [416] Z. Chang, Z. Chen, F. Wu, H. Tang, X.Z. Yuan, H. Wang, Synthesis and characterization of nonspherical LiCoO<sub>2</sub> with high tap density by two-step drying method, *Electrochem. Solid-State Lett.* 11 (12) (2008) A229–A232.
- [417] Z. Chang, Z. Chen, F. Wu, H. Tang, Z. Zhu, X.Z. Yuan, H. Wang, Synthesis and properties of high tap-density cathode material for lithium ion battery by the eutectic molten-salt method, *Solid State Ionics* 179 (2008) 2274–2277.
- [418] H. Ren, Y. Wang, D. Li, L. Ren, Z. Peng, Y. Zhou, Synthesis of LiNi<sub>1/3</sub>Co<sub>1/3</sub>Mn<sub>1/3</sub>O<sub>2</sub> as a cathode material for lithium battery by the rheological phase method, *J. Power Sources* 177 (2008) 439–444.
- [419] B.-J. Hwang, K.-F. Hsu, S.-K. Hu, M.-Y. Cheng, T.-C. Chou, S.-Y. Tsay, R. Santhanam, Template-free reverse-micelle process for the synthesis of a rod-like LiFePO<sub>4</sub>/C composite cathode material for lithium batteries, *J. Power Sources* 194 (2009) 515–519.
- [420] E. Hosono, T. Kudo, I. Honma, H. Matsuda, H. Zhou, Synthesis of single crystalline spinel LiMn<sub>2</sub>O<sub>4</sub> nanowires for a lithium ion battery with high power density, *Nano Lett.* 9 (3) (2009) 1045–1051.
- [421] H. Fang, L. Li, Y. Yang, G. Yan, G. Li, Low-temperature synthesis of highly crystallized LiMn<sub>2</sub>O<sub>4</sub> from alpha manganese dioxide nanorods, *J. Power Sources* 184 (2008) 494–497.
- [422] H. Gabrisch, J. Wilcox, M.M. Doeff, TEM study of fracturing in spherical and plate-like LiFePO<sub>4</sub> particles, *Electrochem. Solid-State Lett.* 11 (3) (2008) A25–A29.
- [423] C. Deng, S. Zhang, B. Wu, S.Y. Yang, H.Q. Li, Synthesis and characteristics of nanostructured Li(Co<sub>1/3</sub>Ni<sub>1/3</sub>Mn<sub>1/3</sub>)O<sub>2</sub> cathode material prepared at 0 °C, *J. Solid State Electrochem.*, in press, doi:10.1007/s10008-009-0874-6.
- [424] H. Chen, C.P. Grey, Molten salt synthesis and high rate performance of the “Desert-Rose” form of LiCoO<sub>2</sub>, *Adv. Mater.* 20 (2008) 2206–2210.
- [425] N.J. Dudley, Thin film micro-batteries, *ECS Interface* 17 (3) (2008) 44–48.
- [426] S.-W. Song, S.-W. Baek, H.Y. Park, Y.C. Lim, K.C. Lee, Structural changes in a thin-film lithium battery during initial cycling, *Electrochem. Solid-State Lett.* 11 (5) (2008) A55–A59.



- [427] C.-N. Li, J.-M. Yang, V. Krasnov, J. Arias, K.-W. Nieh, Phase transformation of nanocrystalline LiCoO<sub>2</sub> cathode after high-temperature cycling, *Electrochem. Solid-State Lett.* 11 (5) (2008) A81–A83.
- [428] J. Xie, N. Imanishi, T. Matsumura, A. Hirano, Y. Takeda, O. Yamamoto, Orientation dependence of Li-ion diffusion kinetics in LiCoO<sub>2</sub> thin films prepared by RF magnetron sputtering, *Solid State Ionics* 179 (2008) 362–370.
- [429] J.M. Kim, G.B. Park, K.C. Lee, H.Y. Park, S.C. Nam, S.W. Song, Li–B–O–N electrolytes for all-solid-state thin film batteries, *J. Power Sources* 189 (2009) 211–216.
- [430] C.T. Ni, K.Z. Fung, Effect of chitosan on deposition of LiCoO<sub>2</sub> thin film for Li-ion batteries, *Solid State Ionics* 180 (2009) 900–903.
- [431] T. Doi, M. Inaba, Y. Iriyama, T. Abe, Z. Ogumi, Electrochemical STM observation of Li<sub>1-x</sub>Mn<sub>2-x</sub>O<sub>4</sub> thin films prepared by pulsed laser deposition, *J. Electrochem. Soc.* 155 (1) (2008) A20–A23.
- [432] J. Xie, K. Kohno, T. Matsumura, N. Imanishi, A. Hirano, Y. Takeda, O. Yamamoto, Li-ion diffusion kinetics in LiMn<sub>2</sub>O<sub>4</sub> thin films prepared by pulsed laser deposition, *Electrochim. Acta* 54 (2008) 376–381.
- [433] S.B. Tang, M.O. Lai, L. Lu, Study on Li-ion diffusion in nano-crystalline LiMn<sub>2</sub>O<sub>4</sub> thin film cathode grown by pulsed laser deposition using CV, EIS and PITT techniques, *Mater. Chem. Phys.* 111 (2008) 149–153.
- [434] J. Xie, T. Tanaka, N. Imanishi, T. Matsumura, A. Hirano, Y. Takeda, O. Yamamoto, Li-ion transport kinetics in LiMn<sub>2</sub>O<sub>4</sub> thin films prepared by radio frequency magnetron sputtering, *J. Power Sources* 180 (2008) 576–581.
- [435] D.W. Shin, J.-W. Choi, W.-K. Choi, Y.S. Cho, S.-J. Yoon, XPS/EXAFS study of cycleability improved LiMn<sub>2</sub>O<sub>4</sub> thin film cathodes prepared by solution deposition, *Electrochem. Commun.* 11 (2009) 695–698.
- [436] T. Matsumura, N. Imanishi, A. Hirano, N. Sonoyama, Y. Takeda, Electrochemical performances for preferred oriented PLD thin-film electrodes of LiNi<sub>0.8</sub>Co<sub>0.2</sub>O<sub>2</sub>, LiFePO<sub>4</sub> and LiMn<sub>2</sub>O<sub>4</sub>, *Solid State Ionics* 179 (2008) 2011–2015.
- [437] B. Dunn, J.W. Long, D.R. Rolison, Rethinking multifunction in three dimensions for miniaturizing electrical energy storage, *ECS Interface* 17 (3) (2008) 49–53.
- [438] P.H.L. Notten, F. Roozeboom, R.A.H. Niessen, L. Baggetto, 3-D integrated all-solid-state rechargeable batteries, *Adv. Mater.* 19 (2007) 4564–4567.
- [439] F. Cheng, Z. Tao, J. Liang, J. Chen, Template-directed materials for rechargeable lithium-ion batteries, *Chem. Mater.* 20 (3) (2008) 667–681.
- [440] H. Uchiyama, E. Hosono, H. Zhou, H. Imai, Three-dimensional architectures of spinel-type LiMn<sub>2</sub>O<sub>4</sub> prepared from biomimetic porous carbonates and their application to a cathode for lithium-ion batteries, *J. Mater. Chem.* 19 (2009) 4012–4016.
- [441] W. Zhou, W. He, Z. Li, H. Zhao, S. Yan, Biosynthesis and electrochemical characteristics of LiFePO<sub>4</sub>/C by microwave processing, *J. Solid State Electrochem.*, in press, doi:10.1007/s10008-008-0762-5.
- [442] Y.J. Lee, H. Yi, W.-J. Kim, K. Kang, D.S. Yun, M.S. Strano, G. Ceder, A.M. Belcher, Fabricating genetically engineered high-power lithium-ion batteries using multiple virus genes, *Science* 324 (2009) 1051–1055.
- [443] K.T. Nam, D.-W. Kim, P.J. Yoo, C.-Y. Chiang, N. Meethong, P.T. Hammond, Y.-M. Chiang, A.M. Belcher, Virus-enabled synthesis and assembly of nanowires for lithium ion battery electrodes, *Science* 312 (2006) 885–888.