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Effect of high temperature environment on the performance of $LiNi_{0.5}Co_{0.2}Mn_{0.3}O_2$ battery

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ABSTRACT

Thermal generation behavior of 18650 ternary $LiNi_{0.5}Co_{0.2}Mn_{0.3}O_2$ batteries was tested at working environment of 30 and 50 °C, respectively. The experimental results showed that the surface temperature difference of the battery at high temperature of 50 °C and its corresponding heating rate were both higher than those at 30 °C owing to the increased internal resistance, which also led to a decrease of lithium storage capacity obviously. By characterizing the crystal/nano structure of the ternary cathode materials, these phenomena could be ascribed to the damage of the crystal structure and aggregation of the electrode materials.

1. Introduction

Lithium ion batteries (LIBs) have attracted intense attention in many applications, ranging from portable electronics to electric vehicles over the past decade owing to their non-toxicity, high energy density and long cycle life compared to traditional secondary batteries such as Ni-MH and lead acid batteries [1–4]. To meet the increasing demand of LIBs with high energy density, it is a hotspot and difficulty to develop electrode materials with long cycle life, high security and capacity.

Ternary cathode materials of $LiNi_{0.5}Co_{0.2}Mn_{0.3}O_2$ (NCM523) [5] have been proven superior to traditional cathode materials such as $LiCoO_2$ [6–8] and $LiFePO_4$ [9,10] because of their isostructural to α-$NaFeO_2$, whose 3b site is filled by most of metal ions [11]. However, such a ternary cathode always presents poor thermal performance at high temperature of 45–70 °C [12], leading to a decreasing capacity during repeated charge–discharge cycles [13]. During the charge–discharge process, temperature rises sharply. Combining with the high initial (environmental) temperature, the excessively high working temperature may result in destruction of the battery materials, thus leading to severe capacity fading. In extreme cases, safety problems, such as flatulence and explosion, occur as heat builds up uncontrollably, that is, thermal runaway. Wen Liu [14] investigated the electrochemical performance of NCM523 battery at high temperature of 53 °C and found that after 100 cycles, the capacity decreased from 180 to 85 mAh g^{-1} (47.2%). Yue Xu [15] reported that the capacity of NCM523 battery reduced by 35% after 10 cycles at 55 °C. Xuning Feng [16] investigated the heat generation of NCM battery in an adiabatic ambient, and found that the inside temperature rose to 870 °C uncontrollably because thermal runaway happened. Nevertheless, the root cause of the above phenomenon has not been investigated from a materials science point of view yet. This will undoubtedly limit the performance optimization and commercialization of the ternary cathode batteries greatly.

Therefore, in this manuscript, for the first time, we investigate the root cause of the decreased electrochemical/thermal performance on NCM523 battery by establishing the relevance between the crystal/nano structure of the ternary cathode materials and their electrochemistry/thermal performance. The experimental results show that the nanostructure and crystal structure of NCM523 cathode materials are both destroyed severely at high ambient temperature of 50 °C, thereby resulting in a more obviously decreasing capacity and higher heating rate as compared with that working at low ambient temperature of 30 °C. We believe that this structure-performance relationship investigation may provide a certain basis for further optimizing the electrochemical and thermal performances of NCM523 cathode materials.

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Nomenclature

Parameter	*The meaning of parameter*	HTB	high temperature battery
LIBs	lithium ion batteries	SOC	state of Charge
NCM523	$LiNi_{0.5}Co_{0.2}Mn_{0.3}O_2$	ΔT	difference temperature
DMC	dimethyl carbonate	Rr	internal resistance of battery
RTB	room temperature battery	XRD	X-ray diffraction
NB	normal battery	SEM	scanning electron microscopy

2. Experimental

2.1. Materials

All of the charge–discharge experiments were carried out on two NCM523 batteries (YJDL P18650 N, 1500 mAh) in an electric incubator (SKP02.250, Yan Ling Electric Co., Ltd.). This type of 18650 batteries comprises NCM523 cathode, graphite anode, $LiPF_6$ electrolyte and ceramic membrane separator. Both the batteries were charged under constant current and constant voltage protocol. Subsequently, the first battery was discharged at 10 C under room temperature of 30 °C and denoted as room temperature battery (RTB), while the second one was discharged at 10 C under relatively high temperature of 50 °C, which was denoted as high temperature battery (HTB). For comparison, another NCM523 battery without charge–discharge cycles was denoted as normal battery (NB).

2.2. Electrochemical measurements

A battery internal resistance meter (YR1030) was used to measure the internal resistance at different state-of-charge (SOC) during the discharge process of 10 C after 50 cycles.

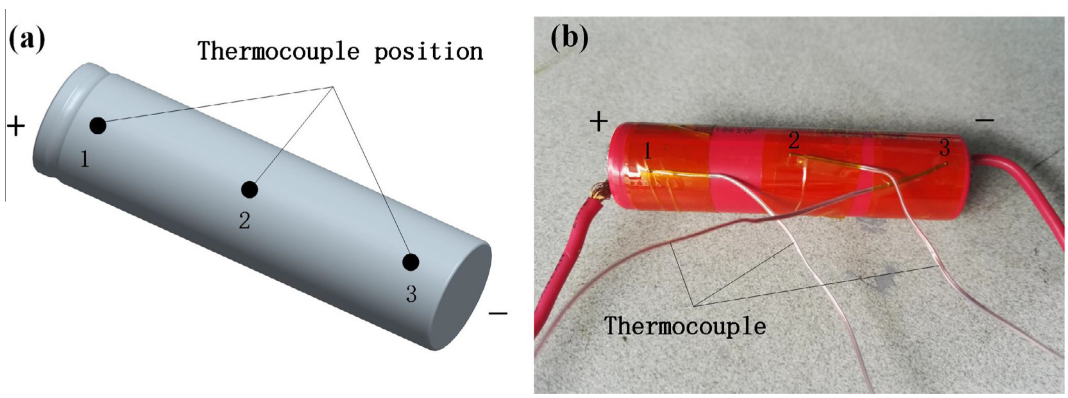

Fig. 1. (a) Schematic and (b) actual diagrams of the thermocouples' location.

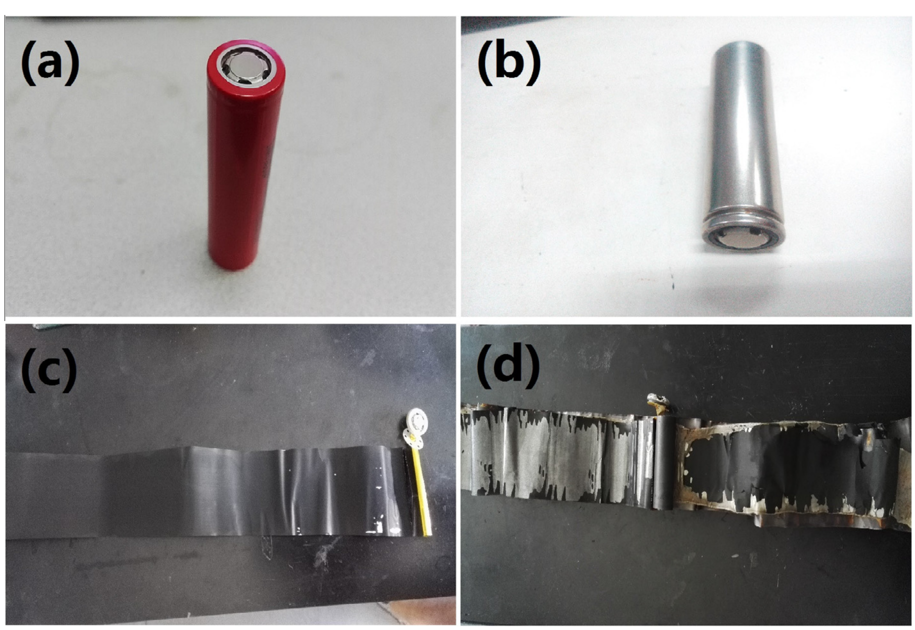

Fig. 2. (a) 18650 NCM523 battery, (b) 18650 NCM523 battery without heat shrink wrapping, (c) cathode material coated on the current collector of NB, and (d) cathode material coated on the current collector of HTB.