

# Preparation of $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$ in certain oxygen pressure<sup>①</sup>

LI Hui(李 辉)<sup>1,2</sup>, ZHAI Yu-chun(翟玉春)<sup>1</sup>, TIAN Yan-wen(田彦文)<sup>1</sup>

(1. School of Materials and Metallurgy, Northeastern University, Shenyang 110004, China;

2. School of Petroleum and Chemical Engineering,

Liaoning University of Petroleum and Chemical Technology, Shenyang 113001. China)

**Abstract:** The  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  as cathode material of lithium ion battery was prepared by solid reaction at high temperature and oxygen pressure. The influences of the prepared conditions on electrochemical properties of products were discussed which include the pressure of oxygen, synthesis time and temperature as well as the molar ratio of the raw materials. The optimal synthetic conditions are as follows: reactive time is 8 h and 10 h; oxygen pressure is 0.20 MPa; reactive temperature is 800 °C; and molar ratio of the reactants is  $\text{Li}:\text{Ni}:\text{Co} = 1.2:0.9:0.1$ .  $\text{LiNi}_{0.9}\text{Co}_{0.1}\text{O}_2$  was synthesized with the perfect crystal structure and the good electrochemical properties. Its discharged capacity is up to 189.4 mAh/g. The results of X-ray diffraction and SEM analysis reveal that the product presents a layered structure of  $\text{LiNiO}_2$ . The increase of the oxygen pressure during the reactive processes has important effects on the structure and electrochemical properties of the product.

**Key words:** lithium ion battery; cathode material  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$ ; oxygen pressure; optimal synthetic condition

**CLC number:** TM 910.1

**Document code:** A

## 1 INTRODUCTION

Lithium ion battery is the newly developed rechargeable battery subsequent to Cd/Ni and MH/Ni battery. Its high energy property is not only fit for the power supply of small scale electric product developing at top speed, but also fit for the power supply of the large scale motive power tool to avoid polluting the environment. The preparation of cathode material is the key links for the development of lithium ion battery. At present, the cathode materials used in lithium ion battery are  $\text{LiCoO}_2$ ,  $\text{LiNiO}_2$ ,  $\text{LiMn}_2\text{O}_4$  and their derivatives. Among them,  $\text{LiCoO}_2$  has been used extensively, but it is restricted to develop because of its high cost. The electrochemical properties of  $\text{LiNiO}_2$  are similar with  $\text{LiCoO}_2$ , and  $\text{LiNiO}_2$  has obvious price superiority. Therefore, it catches more attention by many scholars all over the world. But the synthesis of stoichiometric  $\text{LiNiO}_2$  is difficult, which is still in studying stage of laboratory. Consequently, a large amount of research focus on the synthesis of oxide compounds of  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  since they have extremely similar crystal structure with  $\text{LiCoO}_2$  and  $\text{LiNiO}_2$  and certain superiority in electrochemical capacity, cycling property and cost<sup>[1-15]</sup>. However, the electrochemical properties of  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  have not got remarkable improvement than  $\text{LiNiO}_2$  up to present. In this paper,  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  is synthesized at a certain pressure in a closed system and pure oxygen atmosphere. The optimal synthesis conditions for get-

ting perfect crystal structure and good electrochemical properties of the new products are obtained.

## 2 EXPERIMENTAL

### 2.1 Synthesis of $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$

$\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  samples were prepared by solid-state reaction from stoichiometric mixture of  $\text{LiOH}$ ,  $\text{Ni}(\text{OH})_2$  and  $\text{Co}_3\text{O}_4$  as starting materials with a molar ratio of  $\text{Li}:\text{Ni}:\text{Co} = 1.2:0.9:0.1$ . After mixture and ball grinding, the powders were pressed to the pieces under 3-4 MPa, then the pieces were calcined at 600 °C with flowing oxygen for 8h as the first homothermal stage. Then, the pieces were cooled and ground again for sufficient mixing, pressed to pieces once again, and calcined at 750 °C in a closed system and pure oxygen atmosphere for 10 h as the second homothermal stage. Three kinds of samples were synthesized by changing the oxygen pressure at 0.15, 0.20 and 0.25 MPa respectively.

Holding the oxygen pressure at 0.20 MPa, three kinds of samples were synthesized by changing the reactive temperature of the second homothermal stage in 750, 800 and 850 °C respectively.

Holding the oxygen pressure at 0.20 MPa and the reactive temperature of the second homothermal stage at 750 °C, three kinds of samples were synthesized by changing the molar ratio of the reactants with 1.2:0.9:0.1, 1.2:0.8:0.2 and 1.2:0.7:0.3 respectively.

① **Foundation item:** Project(G810300702) supported by Liaoning Fund Committee

**Received date:** 2002 - 09 - 28; **Accepted date:** 2002 - 12 - 16

**Correspondence:** ZHAI Yu-chun, PhD, Professor; Tel: + 86-24-83687731; E-mail: zhai-li4019@sina.com

Holding the oxygen pressure at 0.20 MPa and the reactive temperature of the second homothermal stage at 750 °C, three kinds of samples were synthesized by changing the reactive time of the two homothermal stages with 6 h and 12 h, 8 h and 10 h, 10 h and 8 h respectively.

## 2.2 Orthogonal experiment

$\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  samples were prepared by adopting two homothermal stages and by increasing oxygen pressure technique. In order to obtain optimal synthesis conditions of the cathode material, Latin orthogonal experiment was applied with  $L_9(3^4)$ , ignoring the interactions of each factor and choosing the discharge capacity of  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  as the property index, as shown in Table 1.

## 2.3 Measurements

Using  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  as a cathode material, lithium metal plate as an anode, 1 mol/L  $\text{LiPF}_6$  (EC + DMC, 1:1) as an electrolyte, Celgard-2300 polypropylene as the cell septum, nickel net as the flow concentrator of cathode, carbon powder as a conductive agent and PVDF as a binder, the testing cells were fabricated in a glove box filling with Ar gas to examine the electrochemical properties of  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  with DC-5 battery testing instrument. The testing of charge and discharge circle were carried out at a constant current density of 0.5 mA/cm<sup>2</sup>. The crystal structure and phase were identified by X-ray diffractometer with  $\text{CuK}\alpha$ . The microstructure of  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  was observed with JSM-6301F field emission scanning electron microscope.

## 3 RESULTS AND DISCUSSIONS

### 3.1 Influence of reactive conditions on synthesized $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$

#### 3.1.1 Influence of oxygen pressure

X-ray diffraction (XRD) patterns of synthesizing

$\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  in different oxygen pressures are shown in Fig. 1. No impurity phase was detected in three samples by XRD analysis comparing with that of pure  $\text{LiNiO}_2$  prepared in normal pressure. This is illustrated that the  $\text{Co}^{+3}$  and  $\text{Ni}^{+3}$  ions are evenly distributed in the layered rhombohedral hexagonal structure (R3m) and pure phase solid solutions are obtained. With the increasing of the oxygen pressure, the (003) and (006) Bragg peaks gradually become strong in intensity. It is well known that the sensitive parameters for the cation order in  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  solid solutions are the intensity ratios of (003)/(104) and (102)(006)/(101) of X-ray diffraction peak. Lithium and nickel or cobalt in alternating layers distribute evenly will lead to an increase of the intensity ratios respectively. The increasing of the oxygen pressure is beneficial to improve the crystal structure of  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$ . Nevertheless, when oxygen pressure increases to 0.25 MPa, the Bragg peaks pattern has no clearly changed corresponding to the one in 0.20 MPa.

#### 3.1.2 Influence of reactive temperature

X-ray diffraction patterns of synthesized  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  at different reactive temperatures are shown in Fig. 2. With the increasing of the reactive temperature, all the peaks illustrate that the pure phase solid solutions of the layered rhombohedral hexagonal structure obtained through the (104) peak are slightly intensified when the temperature is over 750 °C, which presents that the synthesis at 750 °C is suitable to get perfect crystal structure of  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$ .

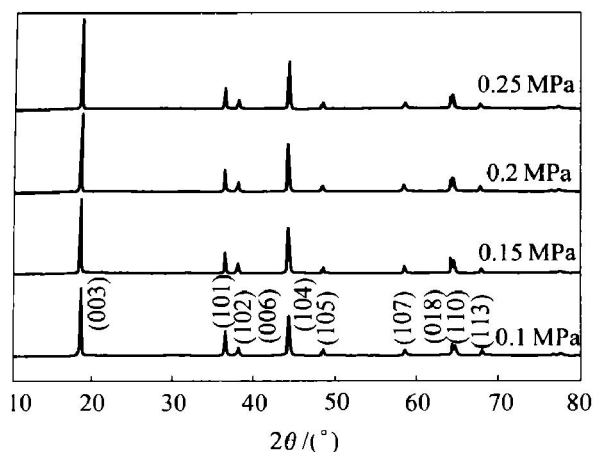
#### 3.1.3 Influence of molar ratios of reactants

Taking into account the lithium salt volatility, a slightly excess lithium content was mixed in the reactants to compensate for the lithium loss, i. e. the molar ratio of  $x(\text{Li}) / x(\text{Ni}) + x(\text{Co}) = 1.2$ . The mixtures were calcined and washed to remove the unreacted lithium compounds.

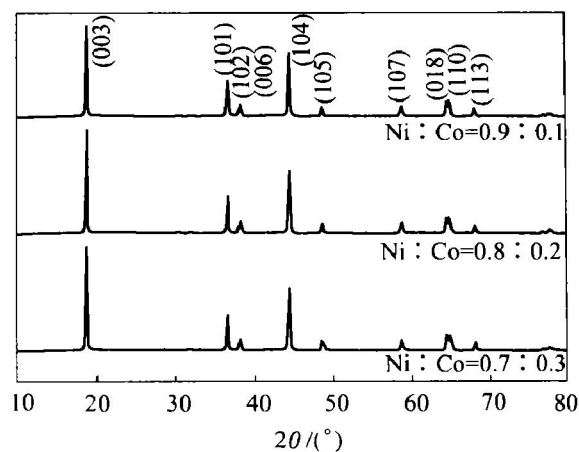
X-ray diffraction patterns of synthesized  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  in different molar ratios are shown

**Table 1**  $L_9(3^4)$  design for orthogonal experiment

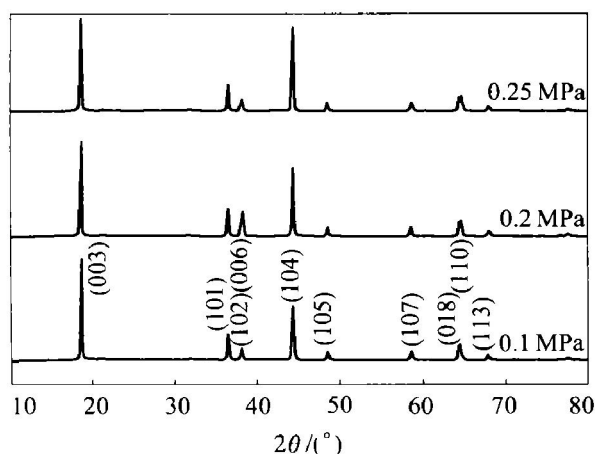
Level	Oxygen pressure (A)/MPa	Temperature of the second stage(B)/°C	Time of two stages (C)/h	Molar ratio of Li Ni Co(D)
1	0.15	750	6, 12	1.2:0.95:0.05
2	0.15	800	8, 10	1.2:0.9:0.1
3	0.15	850	10, 8	1.2:0.8:0.2
4	0.20	750	8, 10	1.2:0.8:0.2
5	0.20	800	10, 8	1.2:0.95:0.05
6	0.20	850	6, 12	1.2:0.9:0.1
7	0.25	750	10, 8	1.2:0.9:0.1
8	0.25	800	6, 12	1.2:0.8:0.2
9	0.25	850	8, 10	1.2:0.95:0.05



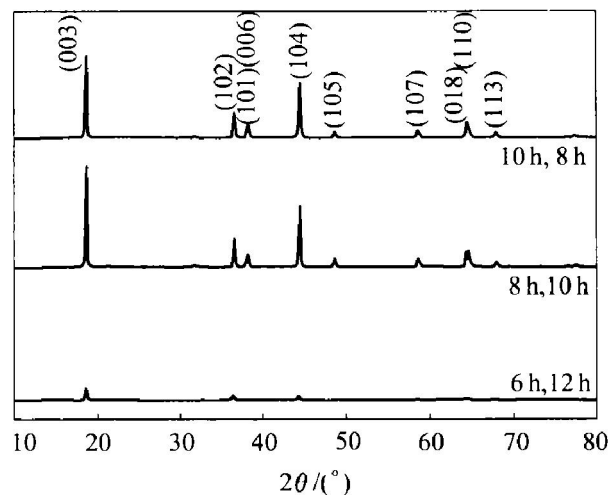
**Fig. 1** XRD patterns of  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  at different oxygen pressures



**Fig. 3** XRD patterns of  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  in different molar ratios of Li : Ni : Co



**Fig. 2** XRD patterns of  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  at different reactive temperatures



**Fig. 4** XRD patterns of  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  with different reactive times

in Fig. 3. All the patterns indicate that the pure-phase solid solutions of the layered rhombohedral hexagonal structure are obtained, but the (003) Bragg peak is gradually intensified with the increase of cobalt content, so the crystallinity of the samples is become better.

#### 3.1.4 Influence of reactive time

X-ray diffraction patterns of the synthesized  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  with different reactive times are shown in Fig. 4. It is indicated that there is not perfect crystal structure of  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  to be obtained when reactive time is chosen as 6 h and 12 h. The reason is that the reactive time in the first homothermal stage is not enough resulting in insufficient decomposition of hydroxides, which has considerable influence on the synthesis of the second homothermal stage, therefore, the reactive time in the first stage should be increased to solve this problem. Though the diffraction pattern of 10 h and 8 h is similar to that of 8 h and 10 h, its (003) Bragg peak is slightly weaker. This is because of the shortage of the reactive time in the second homothermal stage. When the reactive time of

two stages is 8 h and 10 h, the ratio of  $I(003)/I(104)$  is over 1.4, which indicates that the perfect crystal structure is obtained.

#### 3.2 Electrochemical properties of $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$

The testing results of  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  prepared at different reactive conditions are listed in Table 2.

No. 1 ~ 3 in Table 2 are stable for the changing of reactive pressure in the second homothermal stage. The values of discharging capacity are notably increased with rising of pressure from 0.15 MPa to 0.20 MPa. It is indicated that electrochemical properties of the products can be strikingly improved by increasing oxygen pressure. Therefore, the new synthetic methods by adopting oxygen pressure as investigative factor are proved possessing good effect. However, the discharging capacity has no notable increased with rising of oxygen pressure from 0.20 MPa to 0.25 MPa. The possible reason is that, there is an optimal pressure value that can contribute maximal effect to electrochemical properties of the products.

**Table 2** Electrochemical properties of products prepared at different reactive conditions

No.	Molar ratio of $\text{Li} : \text{Ni} : \text{Co}$	Oxygen pressure / MPa	Reactive temperature / °C	Time of two stages / h	Discharging capacity in the first cycle/ ( $\text{mAh} \cdot \text{g}^{-1}$ )
1	1.2 : 0.9 : 0.1	0.15	600, 750	8, 10	169
2	1.2 : 0.9 : 0.1	0.20	600, 750	8, 10	183
3	1.2 : 0.9 : 0.1	0.25	600, 750	8, 10	187
4	1.2 : 0.9 : 0.1	0.20	600, 750	8, 10	183
5	1.2 : 0.9 : 0.1	0.20	600, 800	8, 10	176
6	1.2 : 0.9 : 0.1	0.20	600, 850	8, 10	173
7	1.2 : 0.9 : 0.1	0.20	600, 750	8, 10	183
8	1.2 : 0.8 : 0.2	0.20	600, 750	8, 10	186
9	1.2 : 0.7 : 0.3	0.20	600, 750	8, 10	187
10	1.2 : 0.9 : 0.1	0.20	600, 750	6, 12	128
11	1.2 : 0.9 : 0.1	0.20	600, 750	8, 10	183
12	1.2 : 0.9 : 0.1	0.20	600, 750	10, 8	165

No. 4 – 6 in Table 2 are stable for the changing of reactive temperature in the second homothermal stage. The values of discharging capacity decrease slightly with the temperature increasing, this is because of the products decomposed in high temperature resulting in the formation of imperfect crystal structure of the products.

No. 7 – 9 in Table 2 are stable for the changing of the molar ratios when raw materials are mixed. The values of discharging capacity have not been notably increased with increasing cobalt content. The discharging capacity of product was already quite high in contrast to the one of ordinary pressure when the molar ratio of  $\text{Ni} : \text{Co}$  is 0.9 : 0.1. It is indicated that the electrochemical properties of the products prepared under certain pressure can be notably improved by a small amount of cobalt substitute nickel.

No. 10 – 12 in Table 2 are stand for the changing of reactive time in two homothermal stages. The value of the charging capacity is quite low when prepared in 6 h and 12 h, this is because hydroxides insufficient decomposes in the first homothermal stage, resulting in the nonstoichiometric mixture of the oxides as the reactants in the second homothermal stage. The value of charging capacity is also relative low when prepared in 10 h and 8 h, this is because the reactive time in the second stage is not enough to develop perfect crystal structure. The value of discharging capacity is quite high when prepared in 8 h and 10 h, it is indicated that the reactive time in the two homothermal stages should not be too short for getting products with good electrochemical properties.

The results of analyzing electrochemical properties are in accord with the one of analyzing crystal structure, hence, the crystal structure is the key factor which fix the electrochemical properties.

### 3.3 Orthogonal experiment

#### 3.3.1 Result of orthogonal experiment

The experiments were carried out according to the orthogonal design. The results and analysis of partial difference are listed in Table 3.

The primary and secondary order can be obtained by analysis influence factor with partial difference, that is:  $C > A > B > D$ . The optimal combination of the factors and levels is  $C_2$ ,  $A_2$ ,  $B_2$  and  $D_2$ , i. e., the reactive time in two homothermal stages are 8 h and 10 h; the oxygen pressure is 0.20 MPa; the reactive temperature in the second stage is 800 °C; the molar ratio of the reactants is 1.2 : 0.9 : 0.1. Several verification of experiments were carried out under the optimal combination condition. The testing results of electrochemical properties indicate that the new  $\text{LiNi}_{0.9}\text{Co}_{0.1}\text{O}_2$  prepared by verifying experiment has an average charging capacity of 189.4 mAh/g.

According to the above results of orthogonal experiments, it is found that, in the first place, the electrochemical activated properties of  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  is controlled by reactive time. The sufficient and appropriate reactive time should be demanded in two homothermal stages. If the reactive time in the first homothermal stage is shorten, only an insufficient middling can be got. If the reactive time in the second homothermal stage is shorten, the products with unperfect crystal structure can be gotten, which will result in that the electrochemical activated properties of the products is relative low. Hence, the sufficient reactive time in two homothermal stages should be ensured. In the second place, the electrochemical activated properties of products is controlled by the oxygen pressure in the second stage, the reactive temperature in the second stage is increased (from 720 °C to 800 °C) because of rising of oxygen pressure. Furthermore, the electrochemical prop-

**Table 3**  $L_9(3^4)$  orthogonal experiment designs and results

No.	$A / \text{MPa}$	$B / ^\circ\text{C}$	$C / \text{h}$	$D (\text{molar ratio})$	Discharging capacity / ( $\text{mAh} \cdot \text{g}^{-1}$ )
1	0.15	750	6, 12	1.2: 0.95: 0.05	113.5
2	0.15	800	8, 10	1.2: 0.9: 0.1	167.8
3	0.15	850	10, 8	1.2: 0.8: 0.2	137.4
4	0.20	750	8, 10	1.2: 0.8: 0.2	186.1
5	0.20	800	10, 8	1.2: 0.95: 0.05	171.3
6	0.20	850	6, 12	1.2: 0.9: 0.1	135.1
7	0.25	750	10, 8	1.2: 0.9: 0.1	178.2
8	0.25	800	6, 12	1.2: 0.8: 0.2	141.3
9	0.25	850	8, 10	1.2: 0.95: 0.05	165.5

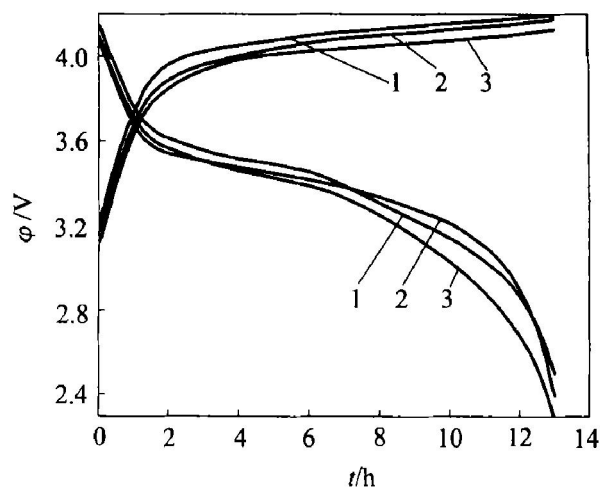
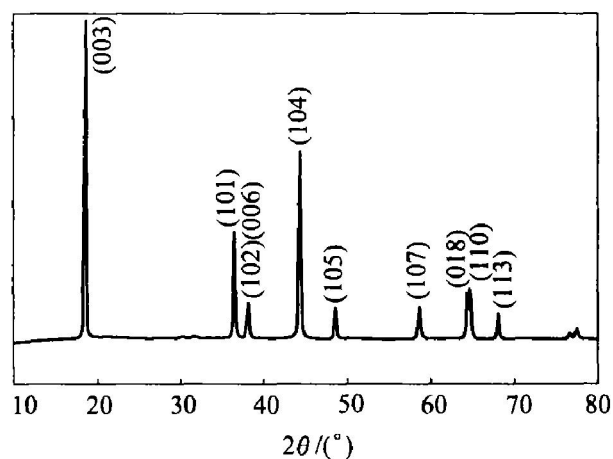
erties of the products are improved notably (from 160  $\text{mAh/g}$  to over 180  $\text{mAh/g}$ ), this is because the crystal structure of the products can be developed perfectly in high temperature. The products will decompose at 800  $^\circ\text{C}$  under normal pressure, rising the oxygen pressure not only makes the crystal structure of products ensured to develop perfectly, but also makes the decomposition of the products restrained. At last, the molar ratio of reactants have the smallest influence on the electrochemical capacity of products. The purpose of adding cobalt to substitute nickel is for decreasing the content of  $\text{Ni}^{2+}$ , which can stabilize the layered structure of  $\text{LiNiO}_2$ , so that it can be benefit to the  $\text{Li}^+$  ion migration. The contents of  $\text{Ni}^{2+}$  in the products prepared under high oxygen pressure and high temperature have been decreased relatively, so that the doping of a small amount cobalt could better improve the crystal structure of the products.

### 3.3.2 Electrochemical properties and crystal structure of $\text{LiNi}_{0.9}\text{Co}_{0.1}\text{O}_2$

The testing cells are fabricated to examine the electrochemical properties of  $\text{LiNi}_{0.9}\text{Co}_{0.1}\text{O}_2$  prepared under the optimal combination condition, the open-circuit voltage of freshly prepared cells are 3.10–3.40 V. Within the voltage of 3.0–4.2 V, the testing of charge and discharge are cycled three times at a constant current of 0.5  $\text{mA/cm}^2$ .

Fig. 5 shows the cycling behavior of testing cells. The curves of  $\text{Li}/\text{LiNi}_{0.9}\text{Co}_{0.1}\text{O}_2$  maintain almost the same shape. The capacity of  $\text{LiNi}_{0.9}\text{Co}_{0.1}\text{O}_2$  can reach 189.4  $\text{mA/cm}^2$  in the first discharge, and then there is a slightly decrease to 188.1 and 183.7  $\text{mA/cm}^2$  respectively following the second and third cycles. The discharge plateau is at 3.5 V or so. It is indicated that the  $\text{LiNi}_{0.9}\text{Co}_{0.1}\text{O}_2$  has good cycling characteristics.

The XRD pattern and SEM micrograph of  $\text{LiNi}_{0.9}\text{Co}_{0.1}\text{O}_2$  are shown in Figs. 6 and 7. As shown in Fig. 6, the location and numbers of peaks are almost the same as the one of pure  $\text{LiNiO}_2$ , but the peaks are quite sharp, and have higher intensities.

**Fig. 5** Three times charge and discharge curves of  $\text{LiNi}_{0.9}\text{Co}_{0.1}\text{O}_2$ **Fig. 6** X-ray diffraction pattern of  $\text{LiNi}_{0.9}\text{Co}_{0.1}\text{O}_2$ 

No impurity phase is detected by XRD analysis, it illustrates that  $\text{Co}^{3+}$  evenly substitutes  $\text{Ni}^{3+}$  sites among  $\text{NiO}_2$  layers. Moreover, it is noted that the ratio of  $I(003)/I(104)$  is over 1.4, while the (006)/(102) and (108)/(110) peaks split clearly, this indicates that the layered  $R\bar{3}m$  hexagonal structure has been obtained, furthermore, the crystallinity of  $\text{LiNi}_{0.9}\text{Co}_{0.1}\text{O}_2$  is much better than that of pure  $\text{LiNiO}_2$ . That is quite in accord with the testing results of elec-



trochemical properties. The SEM morphology of  $\text{LiNi}_{0.9}\text{Co}_{0.1}\text{O}_2$  power illustrates that the average particles size of the powder is about 2  $\mu\text{m}$ , as shown in Fig. 7.



**Fig. 7** Scanning electron micrograph of  $\text{LiNi}_{0.9}\text{Co}_{0.1}\text{O}_2$

#### 4 CONCLUSION

The crystal structure and electrochemical properties of the synthetic materials can be improved significantly by increasing oxygen pressure in a closed reactive system. When the oxygen pressure increases up to a certain value, an ideal cathode material can be synthesized. Furthermore, the reactive temperature in the second homothermal stage also has been increased because of the increasing of oxygen pressure. Therefore the electrochemical properties of  $\text{LiNiO}_2$  can be notably improved by a small amount of Cobalt substitute Nickel.

The optimal synthetic conditions for producing cathode material  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  by Latin orthogonal experiments, i. e. the reactive times in two homothermal stages are 8 h and 10 h; oxygen pressure is 0.20 MPa; the reactive temperature in second homothermal stage is 800  $^{\circ}\text{C}$ ; the molar ratio of reactants is  $\text{Li}:\text{Ni}:\text{Co}=1.2:0.9:0.1$ . Under this condition, we have synthesized cathode material  $\text{LiNi}_{0.9}\text{Co}_{0.1}\text{O}_2$ , which has layered  $\text{R}\bar{3}\text{m}$  hexagonal structure and high crystallinity that is similar with active  $\text{LiNiO}_2$ . Its electrochemical properties have been increased notably, so that the discharge capacity in the first cycle is up to 189.4 mAh/g.

#### REFERENCES

- [1] TIAN Yan-wen, GAO Hong, ZHAI Yu-chun, et al. Preparation and electrochemical behavior of  $\text{Li}_x\text{Ni}_{1-y}\text{Co}_y\text{O}_2$  as cathode materials [J]. Battery Bimonthly, 1999, 29(3): 103 - 106. (in Chinese)
- [2] TIAN Yan-wen, ZHAI Xiu-jing, GAO Hong, et al. Preparation and electrochemical behavior of  $\text{LiNiO}_2$  as cathode materials in secondary lithium ion battery [J]. Journal of Inorganic Materials, 1999, 14(3): 483 - 486. (in Chinese)
- [3] GAO Hong, ZHAI Yu-chun, ZHAI Xiu-jing, et al. Preparation of  $\text{Li}_x\text{NiO}_2$  as cathode in secondary lithium ion battery [J]. Chinese Journal of Function Materials, 1998, 29(5): 555 - 557. (in Chinese)
- [4] GAO Hong, ZHAI Yu-chun, ZHAI Xiu-jing, et al. Preparation of  $\text{LiCoO}_2$  as cathode in secondary lithium battery [J]. The Chinese Journal of Nonferrous Metals, 1998, 8(Suppl 1): 185 - 187. (in Chinese)
- [5] GAO Hong, ZHAI Xiu-jing, ZHAI Yu-chun, et al. Research on preparation of  $\text{LiNiO}_2$  as cathode in secondary lithium ion battery [J]. Chinese Journal of Power Sources, 1999, 23(Suppl.): 53 - 55. (in Chinese)
- [6] GUO Ming-feng, YE Jiu-cai, ZHANG Hong-you, et al. Study on  $\text{LiCo}_{1-x}\text{Ni}_x\text{O}_2$  used as the cathode of lithium ion battery [J]. Chinese Journal of Power Sources, 1999, 23(Suppl.): 47 - 48. (in Chinese)
- [7] ZOU Zheng-guang, MAI Li-qiang, CHEN Hai-yuan, et al. Preparation of  $\text{LiNi}_x\text{Co}_{1-x}\text{O}_2$  cathode materials for Li ion batteries [J]. Battery Bimonthly, 2001, 31(3): 116 - 118. (in Chinese)
- [8] YING Jie-rong, WAN Chun-rong, JIANG Chang-yin, et al. Preparation and characterization of high-density spherical  $\text{LiNi}_{0.8}\text{Co}_{0.2}\text{O}_2$  [J]. J Tsinghua Univ (Sci & Tech), 2001, 41(6): 75 - 77. (in Chinese)
- [9] LIU Ren-min, LUO Jiang-shan, WU Guo-liang, et al. Study on  $\text{LiCo}_{0.5}\text{Ni}_{0.5}\text{O}_2$  used in the cathode of lithium ion battery [J]. Chinese Journal of Power Sources, 1998, 22(3): 104 - 106, 114. (in Chinese)
- [10] ZHAN Hui, ZHOU Yur-hong. Development in cathode materials for lithium ion battery [J]. Chinese Journal of Power Sources, 1999, 23(Suppl.): 102 - 105. (in Chinese)
- [11] Molenda J, Wilk P, Marzec J. Transport properties of the  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  system [J]. Solid State Ionics, 1999, 119(1-4): 19 - 22.
- [12] Li W, Currie J C. Morphology effects on the electrochemical performance of  $\text{LiNi}_{1-x}\text{Co}_x\text{O}_2$  [J]. J Electrochem Soc, 1997, 144(8): 2773 - 2778.
- [13] Choi Young-Min, Pyun Su-II, Moon Seong-In. Effects of cation mixing on the electrochemical lithium intercalation reaction into porous  $\text{Li}_{1-\delta}\text{Ni}_{1-y}\text{Co}_y\text{O}_2$  electrodes [J]. Solid State Ionics, 1996, 89(1-2): 43 - 52.
- [14] Rougier A, Saadouni I, Gravereau P, et al. Effect of cobalt substitution on distribution in  $\text{LiNi}_{1-y}\text{Co}_y\text{O}_2$  electrode materials [J]. Solid State Ionics, 1996, 90(1-4): 83 - 90.
- [15] Banov B, Bourilkov J, Mladenov M. Cobalt stabilized layered lithium-nickel oxides cathodes in lithium rechargeable cells [J]. J Power Sources, 1995, 54(2): 268 - 270.

(Edited by HE Xue-feng)