

Effects of calcination temperature on properties of Li_2SiO_3 for precursor of $\text{Li}_2\text{FeSiO}_4$

LI Xiang-qun¹, GUO Hua-jun², LI Li-ming², LI Xin-hai², WANG Zhi-xing², OU Hui², XIANG Kai-xiong²

1. School of Chemistry and Chemical Engineering, Central South University, Changsha 410083, China;

2. School of Metallurgical Science and Engineering, Central South University, Changsha 410083, China

Received 13 July 2010; accepted 4 October 2010

Abstract: Li_2SiO_3 was synthesized by combination of sol-gel method and calcination at high temperature using Li_2CO_3 , HNO_3 , $\text{Si}(\text{OC}_2\text{H}_5)_4$ and $\text{C}_2\text{H}_5\text{OH}$ as starting materials. The effects of calcination temperature and refluxing system on the composition and properties of lithium silicate were investigated. The samples were characterized by TGA/DTA, XRD, SEM and particle size analysis. $\text{Li}_2\text{FeSiO}_4$ was prepared by the solid-state reaction between Li_2SiO_3 and $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$. The XRD patterns show that the use of refluxing system in the sol-gel preparation can decrease the $\text{Li}_2\text{Si}_2\text{O}_5$ and Li_4SiO_4 impurities in the Li_2SiO_3 sample. The calcination temperature plays an important role in the properties of the Li_2SiO_3 samples. The sample calcined at 700 °C has high purity of 97% Li_2SiO_3 and good morphology as precursor of $\text{Li}_2\text{FeSiO}_4$. It consists of primary particles with size of 1–3 μm , and the primary particle clusters form agglomerates with loose and porous appearance.

Key words: lithium ion batteries; $\text{Li}_2\text{FeSiO}_4$; Li_2SiO_3 ; sol-gel method

1 Introduction

Among the novel cathode materials for lithium ion batteries, iron-based active materials seem to be one of the most ideal candidates. The well-known examples are LiFePO_4 and $\text{Li}_2\text{FeSiO}_4$ distinguished from other materials by their excellent stability [1]. However, the lower electronegativity of Si vs P will result in a lowering of the $\text{Fe}^{\text{II}} \rightleftharpoons \text{Fe}^{\text{III}}$ couple [2]. So $\text{Li}_2\text{FeSiO}_4$ should have a lower electronic band gap, and therefore a higher electronic conductivity compared with LiFePO_4 , and it will become a prospective novel cathode material in lithium ion batteries.

Similar to other cathode materials, one of the important methods for synthesis of $\text{Li}_2\text{FeSiO}_4$ is the solid-state reaction between Li_2SiO_3 and iron compounds at high temperature. For example, NYTÉN et al [2] and ZAGHIB et al [3] have reported the synthesis of $\text{Li}_2\text{FeSiO}_4$ powder by this method using Li_2SiO_3 and $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ as the starting materials.

In previous studies [4–5], the lithium silicates were mainly synthesized by the solid-state reaction,

precipitation and sol-gel methods. By the solid-state reaction between amorphous silica and a lithium compound, lithium silicates were synthesized at high temperature in air [4, 6–7]. But the obtained products were a mixture of Li_2SiO_3 , $\text{Li}_2\text{Si}_2\text{O}_5$, Li_4SiO_4 and quartz compounds. In the precipitation method [4, 8], the reaction between amorphous silica (SiO_2) suspended in water and aqueous solution of LiOH has been proposed. And lithium silicate sample with 87% Li_2SiO_3 was prepared by the precipitation method in Ref. [4]. Compared with the conventional solid-state reaction, the sol-gel method shows advantages in the lower calcination temperature during the synthesis and the higher ionic conductivity for the final Li_2SiO_3 product [9]. This method involves the controlled hydrolysis of an alkoxide and gelation. Gels are prepared by hydrolysis of tetraethylorthosilicate with an alcohol containing a lithium compound such as LiOH , LiNO_3 or CH_3OLi . The properties of the final materials depend remarkably on the factors such as pH, refluxing temperature, initial concentration, reactant stability and impurities. In Ref. [4], the highest content of Li_2SiO_3 (94%) was obtained for molar ratio 2 of Li to Si by sol-gel method.

Foundation item: Project (2007CB613607) support by the National Basic Research Program of China; Project (2010QZZD0101) supported by the Basic Research Foundation for the Chinese Central Universities

Corresponding author: GUO Hua-jun; Tel: +86-731-88836633; E-mail: ghj.csu@163.com

DOI: 10.1016/S1003-6326(11)60747-4

In addition, lithium metasilicate was also synthesized by a modified combustion method using LiOH, SiO₂, H₂O and urea as starting materials [5]. The distinct difference between this method and other ones is that the precursors are only heat-treated at temperatures between 450 and 750 °C for 5 min.

Among those methods, the sol-gel method is the most promising one for the synthesis of Li₂SiO₃. Although many researches have been done on the preparation of lithium metasilicate by the sol-gel method, the effects of the calcination temperature on the properties of Li₂SiO₃ have not been well classified. Furthermore, as a precursor of Li₂FeSiO₄, the Li₂SiO₃ should have a loose and porous morphology, which will facilitate the solid-state reaction between Li₂SiO₃ and iron compounds. In this work, the effects of calcination temperature on the properties of Li₂SiO₃ sample were investigated and Li₂SiO₃ was synthesized with high purity and good morphology, and Li₂FeSiO₄ cathode was prepared using the Li₂SiO₃ precursor.

2 Experimental

Li₂SiO₃ samples were synthesized by the combination of the sol-gel method and the calcination at high temperature. Stoichiometric amounts of Li₂CO₃ and Si(OC₂H₅)₄ were used as the starting materials. Lithium carbonate was dissolved in a nitric acid solution, and then the aqueous solution, alcohol as solubilizing agent, and ethyl orthosilicate [Si(OC₂H₅)₄] were mixed. De-ionized water was added slowly to adjust the solution to pH 2. The mixture was transferred into a refluxing system and heat-treated at 80 °C for 8 h, and then the mixture was aged at 70 °C for 8 h to transform into gel. The gel was dried in a vacuum oven at 120 °C for 24 h and then ground, and the obtained powders were calcined at different temperatures for 8 h.

In order to investigate the effect of refluxing on the characteristics of Li₂SiO₃, a contrast experiment was conducted, where no refluxing was used during the sol-gel preparation and the mixture was directly heated and agitated at 80 °C to vaporize the solvent. The sol-gel transition time of the sample was only 6 h. The other steps were similar to the above ones.

Li₂FeSiO₄ was prepared by solid-state reaction between Li₂SiO₃ and FeC₂O₄·2H₂O. These starting materials were dispersed in acetone, mixed thoroughly and then ground together with 10% (mass fraction) carbon gel. After evaporating the acetone, the mixture was heated to 750 °C for 24 h in Ar atmosphere [3].

The thermo gravimetric analysis and differential thermal analysis (TGA/DTA) were conducted on a Perkin Elmer TGA 7 thermal analyzer. The data were recorded between 20 and 900 °C at a heating rate of 5

°C/min in N₂ atmosphere. The samples were characterized by X-ray diffraction (XRD) on a Rigaku D/max2550VB diffractometer equipped with Cu K_α radiation. The relative volume fractions of the various compounds in the samples were estimated from the total area under the most intense diffraction peak for each phase identified by the corresponding JCPDS files [4]. The morphologies of the samples were observed by a scanning electron microscope (SEM).

3 Results and discussion

The thermo gravimetric analysis and differential thermal analysis were conducted on the dried gel to find suitable calcination temperature for the synthesis of Li₂SiO₃, and the results are shown in Fig.1. The first mass loss occurs below 120 °C, and a corresponding endothermic peak is observed on the DTA curve, which is caused by the dehydration of the sample and the evaporation of remained ethanol. The DTA curve presents a sharp endothermic peak around 250 °C, but little mass loss can be observed on the TGA curve. It is due to the melting of the lithium nitrate. A large mass loss, corresponding to two united endothermic peaks, is detected between 520 and 630 °C. It may result from the polycondensation of silicon hydroxide, the decomposition of lithium nitrate, and the complicated reactions between the lithium compounds and silicon compounds [9–10]. The mass of the sample keeps nearly constant when the temperature is above 630 °C. According to the results of the TGA-DTA, the dried gel was calcined at temperatures between 650 and 900 °C for 8 h in this work.

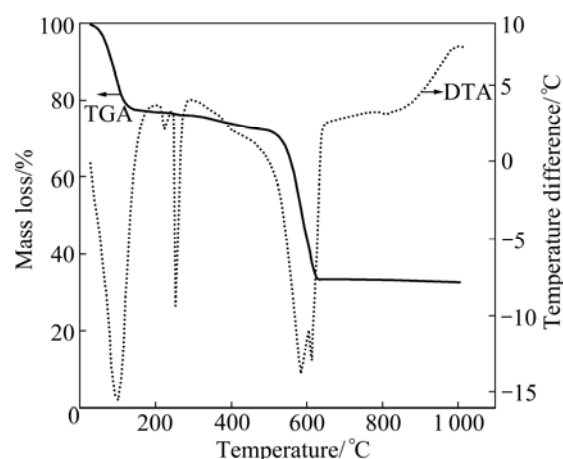


Fig.1 TGA-DTA curves for dry gel at heating rate of 5 °C/min in N₂ atmosphere

Comparisons were made to investigate the effects of refluxing on the properties of Li₂SiO₃. Fig.2 shows the XRD patterns of Li₂SiO₃ samples made with different sol-gel preparation methods. A refluxing system was

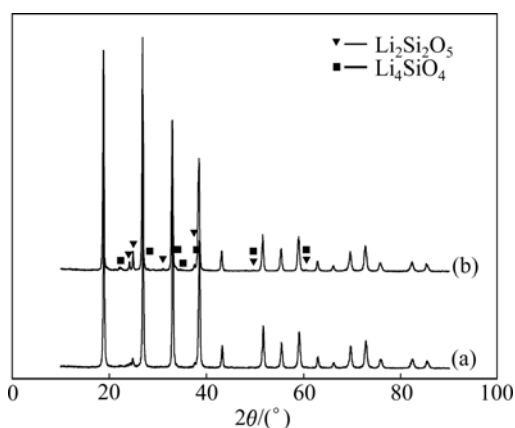


Fig.2 XRD patterns of Li_2SiO_3 samples calcined at 700 °C using refluxing system (a) and without refluxing system (b)

applied in the preparation of sample (a), while not in that of sample (b). The XRD patterns of the two samples can be indexed to the JCPDS file 29–0829 of the *Cmc21* space group structure [11]. Four intense diffraction peaks have been found at 18.9°, 27.0°, 33.0° and 38.5° corresponding to Miller indexes [2 0 0], [1 1 1], [0 2 0] and [3 1 1], where the [1 1 1] plane produces the most intense peak at 27.0. This indicates that Li_2SiO_3 is obtained in both cases. However, the samples are not pure Li_2SiO_3 . A little $\text{Li}_2\text{Si}_2\text{O}_5$ impurity was detected in both samples. To determine the volume fraction, φ , of the compounds detected by XRD, it was assumed that the most intense diffraction peak of each compound was proportional to the volume fraction in the sample, and it was calculated by Eq. (1):

$$\varphi = C_i / \Sigma C_j \quad (1)$$

where C_i represents the integral intensity corresponding to each compound identified, and ΣC_j is the addition of the integral intensity corresponding to all the compounds identified in the sample [4,11–12]. Thus the contents of $\text{Li}_2\text{Si}_2\text{O}_5$ impurity in samples (a) and (b) can be calculated to be 3% and 7%, respectively. Furthermore, a trace amount of Li_4SiO_4 impurity occurred in sample (b). The phase diagram of the Li_2O – SiO_2 system indicates that Li_4SiO_4 and Li_2SiO_3 can coexist and retransform to each other, and so can Li_2SiO_3 and $\text{Li}_2\text{Si}_2\text{O}_5$ [13–14]. The relative content of them depends on the calcination temperature, time, and molar ratio of Li to Si, etc. The higher impurities for the sample without refluxing may be attributed to the locally uneven distribution of lithium in the precursors, which results in the occurrence of Li_4SiO_4 and $\text{Li}_2\text{Si}_2\text{O}_5$ impurities where the lithium is insufficient. The refluxing system prolongs the sol-gel transition time and the compounds are well distributed in the precursor, which facilitates the formation of Li_2SiO_3 and the reduction of impurities during the calcination.

Fig.3 shows the particle size analysis curves for the

samples made with different sol-gel transition methods. Sample (b) without refluxing exhibits a low and broad profile with two united peaks, while sample (a) using the refluxing system shows a much more intense and narrower particle size distribution, which facilitates achieving uniform reactivity of the Li_2SiO_3 precursor and large density of the final $\text{Li}_2\text{FeSiO}_4$ product. The difference in the particle size distribution may be owing to the fact that the refluxing enables the sufficient sol-gel transition and good distribution of compounds, and then suppresses the excess aggregation of the Li_2SiO_3 particles.

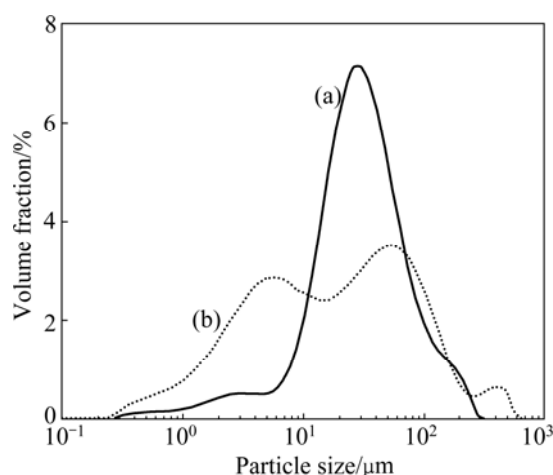


Fig.3 Particle size analysis curves of Li_2SiO_3 samples calcined at 700 °C using refluxing system (a) and without refluxing system (b)

According to the results of XRD and particle size analysis, the use of refluxing system in the sol-gel transition facilitates the preparation of Li_2SiO_3 with high purity and small uniform particles, so the refluxing system was adopted in the following study.

Fig.4 shows the XRD patterns for the Li_2SiO_3 samples synthesized at different temperatures for 8 h. The XRD patterns of samples fit well with the JCPDS file 29–0829, indicating that Li_2SiO_3 was synthesized in the temperature range of 650–900 °C. However, the contents of Li_2SiO_3 and impurities change dramatically with increasing the calcination temperature. The peaks of Li_4SiO_4 are most intense in the sample calcined at 650 °C, and the least intense in the sample calcined at 700 °C. On the other hand, the peaks of $\text{Li}_2\text{Si}_2\text{O}_5$ are most intense in sample calcined at 900 °C, and the least intense in the sample calcined at 700 °C. The samples synthesized at 650, 700, 800 and 900 °C have Li_2SiO_3 contents of 92%, 97%, 88%, 88%, and $\text{Li}_2\text{Si}_2\text{O}_5$ contents of 4%, 3%, 11% and 12%, respectively. Furthermore, 4% Li_4SiO_4 was also found in the sample calcined at 650 °C and trace amounts of Li_4SiO_4 impurity was found in the samples calcined at 800 and 900 °C. The results indicate that the

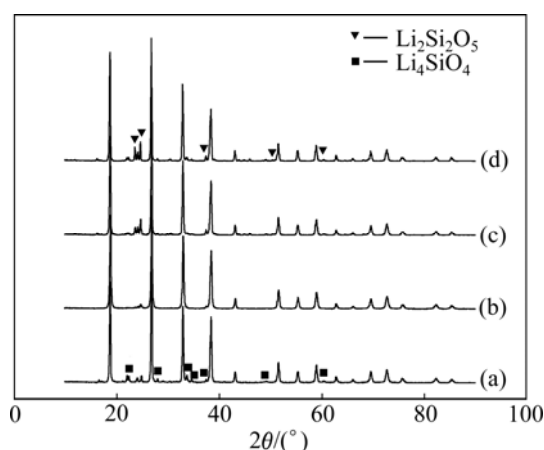


Fig.4 XRD patterns of Li_2SiO_3 samples calcined at 650 °C (a), 700 °C (b), 800 °C (c) and 900 °C (d)

Li_4SiO_4 impurity mainly occurs in the sample synthesized at 650 °C, and the content of $\text{Li}_2\text{Si}_2\text{O}_5$ impurity rises with increasing calcination temperature. The occurrence of Li_4SiO_4 phase and a large amount of $\text{Li}_2\text{Si}_2\text{O}_5$ impurity can be attributed to the insufficient reaction between the lithium compound and silicon compound at low calcination temperature. As a result, a Li_4SiO_4 phase occurs in the site where the lithium exceeds locally, and a $\text{Li}_2\text{Si}_2\text{O}_5$ phase occurs where the lithium is insufficient. The undesired effects of difference in lithium distribution in the precursors can be overcome by enhancing the calcination temperature, which can improve the diffusion of lithium in the precursor and product. So the purity of the sample synthesized at 700 °C was improved dramatically compared with that synthesized at 650 °C. The content of $\text{Li}_2\text{Si}_2\text{O}_5$ impurity increases with increasing the calcination temperature from 700 to 900 °C, and it can be attributed to the lithium sublimation at high temperature, which results in the insufficiency of lithium compound for the synthesis of Li_2SiO_3 . Therefore, the Li_2SiO_3 sample with the highest purity of 97% was achieved at 700 °C in this work.

Fig.5 shows the SEM images of Li_2SiO_3 samples synthesized at different temperatures. The Li_2SiO_3 powders calcined at 700 °C consist of primary particles of 1–3 μm . The primary particle clusters form agglomerates with loose and porous appearance. The Li_2SiO_3 powders calcined at 800 °C are similar to those at 700 °C, except that the agglomerates and the primary particles become large. However, the Li_2SiO_3 powders calcined at 900 °C show a much more compact surface morphology compared with those obtained at 700 °C or 800 °C. It can be attributed to the calcination of the particles at high temperature.

According to the above results, the Li_2SiO_3 sample synthesized by calcination at 700 °C and using refluxing

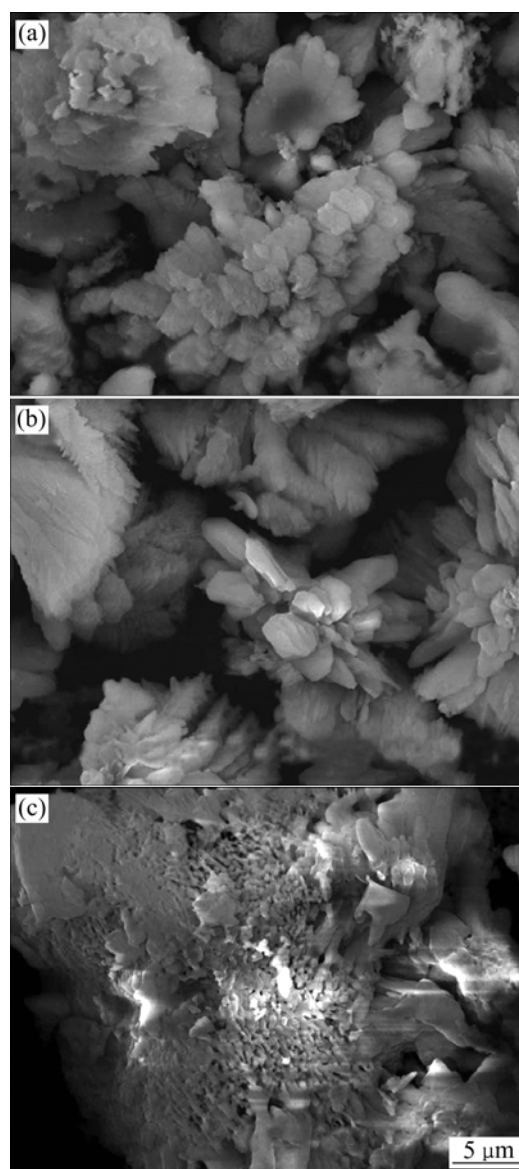


Fig.5 SEM images of Li_2SiO_3 calcined at 700 °C (a), 800 °C (b) and 900 °C (c)

during the sol-gel preparation has excellent properties for the precursor of $\text{Li}_2\text{FeSiO}_4$. The Li_2SiO_3 sample obtained at the optimized conditions shows a high purity of 97% Li_2SiO_3 and a primary particle size of 1–3 μm . It has higher purity and smaller particle size than those reported by PFEIFFER et al[4], where an optimized sample with 94% Li_2SiO_3 and 6% $\text{Li}_2\text{Si}_2\text{O}_5$ impurities was achieved using a similar sol-gel process with refluxing. In addition, a calcination temperature of 900 °C was used[4], which is much higher than that used in this work. The low calcination temperature can prevent serious aggregation of the primary particles and excessive-growth of the crystals and primary particles, which facilitates to improve the reactivity of Li_2SiO_3 precursor in the synthesis of $\text{Li}_2\text{FeSiO}_4$ cathode material.

In order to investigate the suitable calcination

temperature and the possible reactions in the synthesis of $\text{Li}_2\text{FeSiO}_4$ by the solid-state reaction between Li_2SiO_3 and $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$, thermo gravimetric analysis and differential thermal analysis were conducted on the mixture of Li_2SiO_3 and $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ in N_2 atmosphere, and the results are shown in Fig.6. An endothermic peak occurs on the DTA curve around 90 °C and a corresponding mass loss is observed on the TGA curve, which is due to the dehydration of physically absorbed water in the sample. The second endothermic peak is revealed around 180 °C on the DTA curve and corresponds to a continuous mass loss on the TGA curve. It can be attributed to dehydration of the chemically combined water in $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$. In the temperature range of 300–500 °C, the mass of the sample decreases quickly, corresponding to a sharp and intense exothermic peak around 350 °C and two low and broad exothermic peaks around 270 and 500 °C, respectively. This results from the complicated reactions which may include the decomposition of FeC_2O_4 , and the reactions between the iron compounds and the lithium compounds. Above 500 °C, the mass of the sample keeps nearly constant. So it could be concluded that the calcination temperature should be above 550 °C for the synthesis of $\text{Li}_2\text{FeSiO}_4$ powder.

Using the optimized Li_2SiO_3 as a precursor, $\text{Li}_2\text{FeSiO}_4$ was prepared by the solid-state reaction between Li_2SiO_3 and $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ at 750 °C for 24 h. Fig.7 shows the XRD pattern of the $\text{Li}_2\text{FeSiO}_4$ powder. The sharp diffraction peaks indicate that the sample has good crystallinity. The XRD pattern agrees well with that reported by DOMINKO et al[15], and the XRD results for the $\text{Li}_2\text{FeSiO}_4$ phase can be indexed to the orthorhombic unit cell in space group $Pmn21$. However, some unidentifiable impurity peaks were also observed in the diffraction patterns.

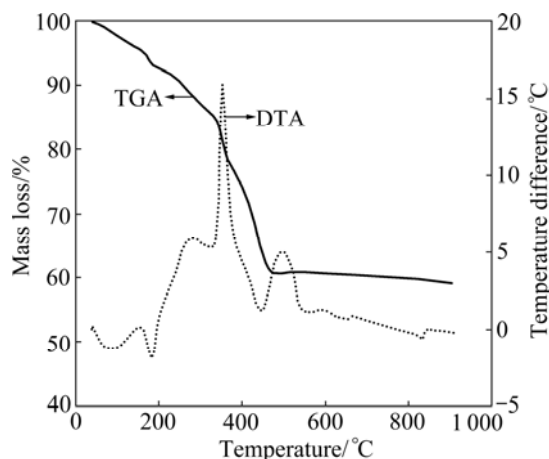


Fig.6 TGA-DTA curves for mixture of Li_2SiO_3 and $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ at heating rate of 5 °C/min in N_2 atmosphere

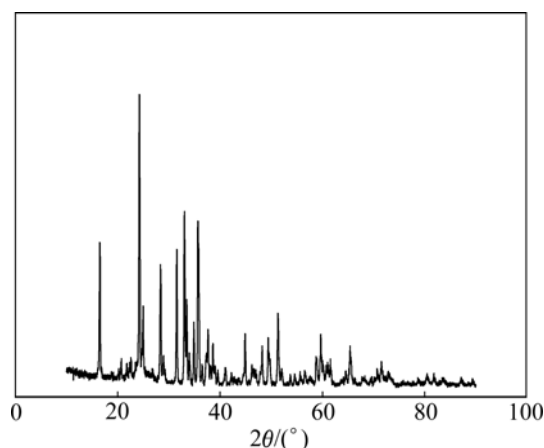


Fig.7 XRD pattern of $\text{Li}_2\text{FeSiO}_4$ sample

4 Conclusions

1) Li_2SiO_3 was synthesized by the combination of sol-gel method and the calcination at high temperature. The use of refluxing system during the sol-gel preparation decreases the $\text{Li}_2\text{Si}_2\text{O}_5$ and Li_4SiO_4 impurities in the Li_2SiO_3 samples.

2) The calcination temperature plays an important role in the properties of Li_2SiO_3 . The purity of the sample synthesized at 700 °C is improved dramatically compared with that synthesized at 650 °C. The content of $\text{Li}_2\text{Si}_2\text{O}_5$ impurity rises with increasing the calcination temperature from 700 to 900 °C, and the Li_2SiO_3 sample with the highest purity of 97% is achieved at 700 °C. The Li_2SiO_3 sample calcined at 700 °C shows a good morphology as the precursor of $\text{Li}_2\text{FeSiO}_4$. It consists of primary particles of 1–3 μm, and the primary particle clusters form agglomerates with loose and porous appearance.

3) $\text{Li}_2\text{FeSiO}_4$ was prepared by the solid-state reaction between Li_2SiO_3 and $\text{FeC}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$. The sample has good crystallinity, and the XRD results can be indexed to the $\text{Li}_2\text{FeSiO}_4$ phase of orthorhombic unit cell in space group $Pmn21$ and some unidentifiable impurity.

References

- [1] DOMINKO R, BELE M, GABERSCEK M, MEDEN A, REMSKAR M, JAMNIK J. Structure and electrochemical performance of $\text{Li}_2\text{MnSiO}_4$ and $\text{Li}_2\text{FeSiO}_4$ as potential Li-battery cathode materials [J]. *Electrochem Commun*, 2006, 8: 217–223.
- [2] NYTÉN A, ABOUIMRANE A, ARMAND M. Electrochemical performance of $\text{Li}_2\text{FeSiO}_4$ as a new Li-battery cathode material [J]. *Electrochem Commun*, 2005, 7: 156–163.
- [3] ZAGHIB K, SALAH A A, RAVETC N, MAUGER A, GENDRON F, JULIEN C M. Structural, magnetic and electrochemical properties of lithium iron orthosilicate [J]. *J Power Sources*, 2006, 160: 1381–1387.

- [4] PFEIFFER H, BOSCH P, BULBULIAN S. Synthesis of lithium silicates [J]. J Nucl Metar, 1998, 257: 309–317.
- [5] CRUZ D, BULBULIAN S. Synthesis of lithium silicate tritium breeder powders by a modified combustion method [J]. J Nucl Metar, 2003, 312: 263–270.
- [6] KNITTERA R, ALM B, ROTH G. Crystallisation and microstructure of lithium orthosilicate pebbles [J]. J Nucl Mater, 2007, 367–370: 1378–1385.
- [7] SAAD K B, HAMZAOUI H, LABIDI A, BESSAIS B. Growth of lithium silicate crystals inside porous silicon film and their exploitation for ozone detection [J]. Appl Surf Sci, 2008, 254: 3955–3960.
- [8] MORALES A A, PFEIFFER H, DELFIN A, BULBULIAN S. Phase transformations on lithium silicates under irradiation [J]. Mater Lett, 2001, 50: 37–41.
- [9] CHEN R F, SONG X Q, MA J F, JIA M Y. Synthesis of Li_2SiO_3 by sol-gel method and study of its ionic conductivity [J]. Materials Review, 1999, 13: 69–74.
- [10] SONG X Q, CHEN R F. Influence of rare-earth oxide dopants on conductivities of Li_2SiO_3 ion conductor [J]. Journal of Functional Material and Devices, 1999, 6: 157–164.
- [11] CRUZ D, BULBULIAN S, LIMA E, PFEIFFER H. Kinetic analysis of the thermal stability of lithium silicates (Li_4SiO_4 and Li_2SiO_3) [J]. J Solid State Chem, 2006, 179: 909–915.
- [12] FU Y P, CHANG C C, LIN C H, CHIN T S. Solid-state synthesis of ceramics in the $\text{BaO-SrO-Al}_2\text{O}_3\text{-SiO}_2$ system [J]. Ceram Int, 2004, 30: 41–47.
- [13] CLAUS S, KLEYKAMP H, SMYKATZ-KLOSS W. Phase equilibria in the $\text{Li}_4\text{SiO}_4\text{-Li}_2\text{SiO}_3$ region of the pseudobinary $\text{Li}_2\text{O-SiO}_2$ system [J]. J Nucl Metar, 1996, 230: 9–15.
- [14] JACQUIN J R, TOMOZAWA M. Crystallization of lithium metasilicate from lithium disilicate glass [J]. J Non-Cryst Solids, 1995, 190: 224–230.
- [15] DOMINKO R, CONTE D E, HANZEL D, GABERSCEK M, JAMNIK J. Impact of synthesis conditions on the structure and performance of $\text{Li}_2\text{FeSiO}_4$ [J]. J Power Sources, 2008, 178: 842–847.

焙烧温度对 $\text{Li}_2\text{FeSiO}_4$ 前驱体 Li_2SiO_3 性能的影响

李向群¹, 郭华军², 李黎明², 李新海², 王志兴², 欧惠², 向楷雄²

1. 中南大学 化学化工学院, 长沙 410083; 2. 中南大学 冶金科学与工程学院, 长沙 410083

摘要: 以 Li_2CO_3 , HNO_3 , $\text{Si}(\text{OC}_2\text{H}_5)_4$ 为原材料, 采用溶胶-凝胶和高温焙烧法合成 Li_2SiO_3 ; 研究焙烧温度和回流系统对硅酸锂组分和性能的影响; 利用 TGA/DTA, XRD, SEM 和粒径分析等手段对样品进行表征; 采用 Li_2SiO_3 和 $\text{Fe}_2\text{C}_2\text{O}_4 \cdot 2\text{H}_2\text{O}$ 固相反应制备 $\text{Li}_2\text{FeSiO}_4$ 。XRD 结果表明, 在溶胶-凝胶制备过程中使用回流系统能减少 Li_2SiO_3 样品中 Li_2SiO_5 和 Li_4SiO_4 杂质。焙烧温度对 Li_2SiO_3 的性能有重要的作用, 当温度为 $700\text{ }^\circ\text{C}$ 时, Li_2SiO_3 前驱体材料样品纯度为 97%, 并具有良好的形貌: 它是由粒径为 $1\sim 3\text{ }\mu\text{m}$ 的一次粒子组成, 一次粒子束形成疏松、多孔的团聚体。

关键词: 锂离子电池; $\text{Li}_2\text{FeSiO}_4$; Li_2SiO_3 ; 溶胶-凝胶法

(Edited by YANG Hua)