

# Low Temperature Synthesis and Characterization of $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$ ( $0 \leq y \leq 1.2$ ) from $\text{V}_2\text{O}_5$ Gel

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Without overnight heating and stirring,  $\text{Li}_{1.2}\text{V}_3\text{O}_8$  and its analogs  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$  ( $0 \leq y \leq 1.2$ ) were successfully synthesized by adding mixed solution of  $\text{LiOH}$  and  $\text{NaVO}_3$  to  $\text{V}_2\text{O}_5$  gel and dehydrating the prepared gel in 150—350 °C. The simplicity awards this synthesis process superiority over other low temperature synthesis routes when mass production is concerned. TG-DTA, XRD and TEM experiments were carried out for physical characterization. By galvanostatic charge-discharge and cyclic voltammetry tests, these products showed better electrochemical performance than high temperature products as cathode active materials in secondary lithium batteries. After treatment of  $\text{Li}_{1.2}\text{V}_3\text{O}_8$  at 250 °C, it exhibited a capacity of 350 mAh/g when cycled at current rate of about 60 mA/g over the voltage range of 3.8—1.7 V vs.  $\text{Li}^+/\text{Li}$ . The influence of partial substitution of Li by Na was also extensively studied.

**Keywords** low temperature synthesis,  $\text{V}_2\text{O}_5$  gel,  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$ , cathode material

## Introduction

Among the three major groups of vanadium oxides,  $\text{V}_2\text{O}_5$ ,  $\text{V}_6\text{O}_{13}$  and  $\text{Li}_{1+x}\text{V}_3\text{O}_8$ , which are suited for cathode materials in lithium rechargeable batteries, the third one has attracted much effort for nearly a quarter of one century since Besenhard and Schöllhorn mentioned its application in 1977.<sup>1</sup> For the electrochemical property of  $\text{Li}_{1+x}\text{V}_3\text{O}_8$  depends much on its preparation method,<sup>2</sup> many investigations have focused on performing new synthesis routes of  $\text{Li}_{1+x}\text{V}_3\text{O}_8$  or new treatments on it, including rapid quenching from the melt,<sup>3</sup> doping of inert nucleation centers like silica or alumina,<sup>4</sup> sufficient grinding,<sup>5</sup> ultrasonical treatment<sup>6</sup> and intercalation of inorganic molecules such as  $\text{NH}_3$ ,  $\text{H}_2\text{O}$  and  $\text{CO}_2$  between layers.<sup>7</sup> Pistoia *et al.*<sup>8</sup> prepared amorphous  $\text{Li}_{1+x}\text{V}_3\text{O}_8$  using a low-temperature solution method. In virtue of the low temperature process employed in their method, the as-prepared material showed an ability to accommodate up to 4.5 mol of  $\text{Li}^+$  ions per formula unit, instead of 3 mol for crystalline  $\text{Li}_{1+x}\text{V}_3\text{O}_8$ . Furthermore, the absence of a long-range crystallographic order reduces the length of the pathways through which  $\text{Li}^+$  ions diffuse. The favorable morphology endows amorphous  $\text{Li}_{1+x}\text{V}_3\text{O}_8$  with a high rate capability. To pursue

the favored benefits brought about by the low-temperature synthesis method, several reformed methods were added to the repertoire. Dai *et al.*<sup>9</sup> obtained  $\text{LiV}_3\text{O}_8$  by the reaction of  $\text{Li}_2\text{CO}_3$  with  $\text{NH}_4\text{VO}_3$  in the range of 300—350 °C, which were blended in an aqueous solution, and Kawakita *et al.*<sup>10</sup> prepared  $\text{Li}_{1+x}\text{V}_3\text{O}_8$  by precipitation technique in  $\text{CH}_3\text{OH}$ . The products thus prepared both possess a smaller grain size and better electrochemical performance than the HT (high temp.) samples prepared by conventional high temperature synthesis.

Sodium vanadate,  $\text{Na}_{1+x}\text{V}_3\text{O}_8$ , has a monoclinic unit cell isostructural with  $\text{Li}_{1+x}\text{V}_3\text{O}_8$ . The presence of  $\text{Na}^+$  ions with larger ionic radii than  $\text{Li}^+$  ions expands the gap between the layers, thus awards  $\text{Na}_{1+x}\text{V}_3\text{O}_8$  with a higher value of chemical diffusion coefficient of lithium and the excellent cycling performance with a higher charge-discharge efficiency.<sup>11</sup> However, both the discharge voltage and the discharge capacity were lower than those of  $\text{Li}_{1+x}\text{V}_3\text{O}_8$ . Therefore, it is assumed that partial substitution of  $\text{Li}^+$  by  $\text{Na}^+$  in  $\text{Li}_{1+x}\text{V}_3\text{O}_8$  could compromise the higher diffusion coefficient of lithium and the higher discharge capacity.<sup>12,13</sup>

In the present research, another new low-temperature synthesis route of  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$  (including  $\text{Li}_{1+x}\text{V}_3\text{O}_8$ ) was proposed, in which mixed solution of  $\text{LiOH}$  and  $\text{NaVO}_3$  was added into  $\text{V}_2\text{O}_5$  gel with mild stirring for only several minutes to prepare  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$  gel.  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$  was obtained by dehydration from this gel in 150—350 °C in air. As-prepared products could be used directly as cathode active materials without further treatments.

## Experimental

### Preparation of LT- $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$

The  $\text{V}_2\text{O}_5$  gel used in this method was prepared by polycondensation of vanadic acid.<sup>14</sup> The vanadic acid without any foreign cations was obtained by passing a metavanadate solution through a bed of a proton exchanging resin. Aqueous  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$  gels were formed by adding mixed solutions

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of LiOH and NaVO<sub>3</sub> with varied concentration ratios to V<sub>2</sub>O<sub>5</sub> gels under mild stirring. Compounds of nominal composition Li<sub>1.2-y</sub>Na<sub>y</sub>V<sub>3</sub>O<sub>8</sub> were obtained by vacuum-drying the gels at 50 °C followed by heating them in the range of 150–350 °C in air. After mild manual grindings in an agate mortar, the products could be used as cathode active materials. For comparison, crystalline Li<sub>1.2</sub>V<sub>3</sub>O<sub>8</sub> was also prepared by the conventional high temperature synthesis.<sup>15</sup>

#### Characterization of LT-Li<sub>1.2-y</sub>Na<sub>y</sub>V<sub>3</sub>O<sub>8</sub> structure

The xerogel vacuum-dried from Li<sub>1.2</sub>V<sub>3</sub>O<sub>8</sub> gel at 50 °C was used in TG and DTA experiments, and the thermal analysis was conducted on a WCT-1A instrument (Beijing Optical Instruments) in air. X-Ray diffraction (XRD) experiments were carried out using a SHIMADZU XRD-6000 X-Ray Diffractometer with Cu K $\alpha$  line. To check the composition of Li<sub>1.2-y</sub>Na<sub>y</sub>V<sub>3</sub>O<sub>8</sub>, the lithium and sodium contents of the samples were determined by inductively coupled plasma atomic emission spectroscopy (ICP-AES) analysis on Thermo-Jarell Ash Autoscan-2000, and the total vanadium content was determined by chemical analysis. For TEM examination, a JEM-100 (XII) microscope was used.

#### Electrochemical property of LT-Li<sub>1.2-y</sub>Na<sub>y</sub>V<sub>3</sub>O<sub>8</sub>

The composite cathode electrode consisted of 80% active material, 15% acetylene black and 5% polytetrafluoroethylene (PTFE) binder. The current collector was a mesh of stainless steel. Lithium disks worked as both counter and reference electrodes, and the separator was Celgard-2400. Three-electrode and two-electrode cells were used in cyclic voltammetry (CV) and galvanostatic charge-discharge tests respectively. Unless specified, the charge and discharge current rate was about 60 mA/g. The electrolyte was 1 mol/L LiClO<sub>4</sub> in blended ethylene carbonate (EC) and dimethyl carbonate (DMC) solution with volumetric ratio of 1:1. The CV tests were carried out on a CHI 660A workstation and the galvanostatic charge-discharge tests on ARBIN BT-2000. All cells were assembled in a glove box (MECAFLEX, MECABOX 80-1 "s") filled with purified argon gas, and tested at 25 °C.

## Results and discussion

#### Structural characterization of LT-Li<sub>1.2</sub>V<sub>3</sub>O<sub>8</sub>

The results of elemental analysis accorded fairly well with the nominal composition of Li<sub>1.2-y</sub>Na<sub>y</sub>V<sub>3</sub>O<sub>8</sub>, and also confirmed the advantage of this low temperature synthesis route over the high temperature synthesis route by exempting the volatilization of light elements.

The XRD profiles in Fig. 1 show that the new synthesis route has really led to the formation of Li<sub>1.2</sub>V<sub>3</sub>O<sub>8</sub>. The X-ray patterns of the products match the pattern of the high-temperature form fairly well (JCPDS Card, 18-754), and with the

temperature increasing, the crystallinity of these products increases. The product treated at 150 °C is somewhat amorphous, but the main diffraction peaks appear gradually over 200 °C. It should be noted that there is a peak around 12° in the sample at 150 °C or 200 °C, which disappears by heating over 250 °C. For V<sub>2</sub>O<sub>5</sub>·*n*H<sub>2</sub>O, water molecules are intercalated between the V<sub>2</sub>O<sub>5</sub> ribbons and the layer distance decreases with the decrease of the amount of water. A V<sub>2</sub>O<sub>5</sub>·1.8H<sub>2</sub>O xerogel with *d* = 1.15 nm was obtained when V<sub>2</sub>O<sub>5</sub> gel was dried at room temperature, and a V<sub>2</sub>O<sub>5</sub>·0.5H<sub>2</sub>O with *d* = 0.87 nm when treated around 250 °C.<sup>16</sup> So the peak around 12° (*d* = 0.737 nm) is unlikely to be the (001) peak of V<sub>2</sub>O<sub>5</sub> xerogel. This suggests that Li<sub>1.2</sub>V<sub>3</sub>O<sub>8</sub> xerogel formed from V<sub>2</sub>O<sub>5</sub> gel is somewhat different from V<sub>2</sub>O<sub>5</sub> xerogel.

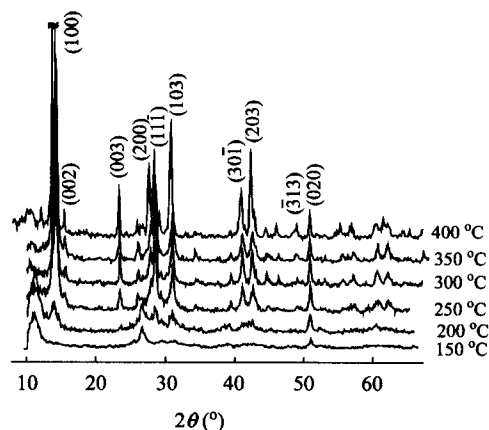


Fig. 1 XRD patterns of Li<sub>1.2</sub>V<sub>3</sub>O<sub>8</sub> with different heating temperature.

Fig. 2 shows the TG-DTA curves of the xerogel obtained by vacuum-drying the Li<sub>1.2</sub>V<sub>3</sub>O<sub>8</sub> gel at 50 °C. It can be found that the compound lost weight gradually from 50 °C, and 20.01% weight of it was lost until 350 °C. This means that the Li<sub>1.2</sub>V<sub>3</sub>O<sub>8</sub> xerogel vacuum-dried at 50 °C could be termed as Li<sub>1.2</sub>V<sub>3</sub>O<sub>8</sub>·4H<sub>2</sub>O. The DTA trace shows two endothermic peaks at 72 °C and 174 °C corresponding to the removal of loosely bound water and part of tightly bound water respectively. The exothermic peak at 322 °C should be assigned to the crystallization of LT-Li<sub>1.2</sub>V<sub>3</sub>O<sub>8</sub>.<sup>8</sup> The TEM images in Fig. 3

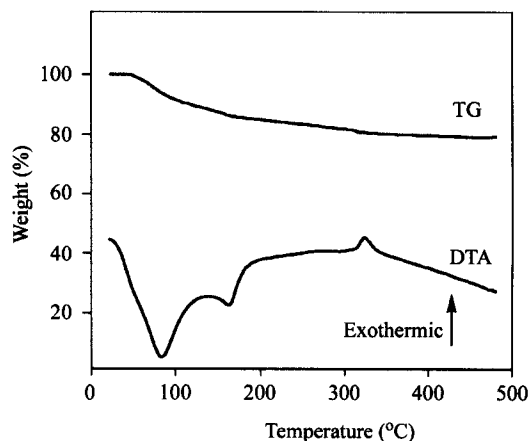
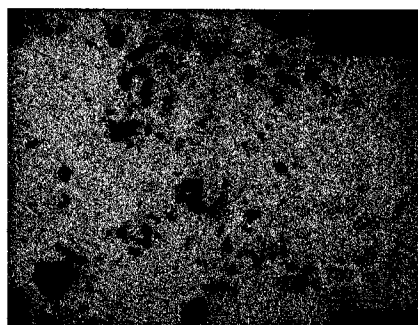


Fig. 2 TG-DTA curves of Li<sub>1.2</sub>V<sub>3</sub>O<sub>8</sub> vacuum-dried at 50 °C, 5 °C/s in air.

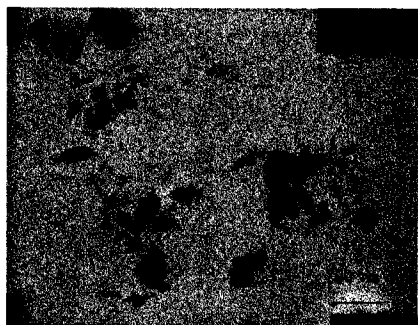
also confirm it. Fig. 3a shows an aggregation of  $\text{Li}_{1.2}\text{V}_3\text{O}_8$  particles. With the increasing of treating temperature, the aggregation collapses into little ones, as seen in Fig. 3b, and then the crystallization occurs with the particle size growing bigger (Fig. 3c, Fig. 3d).



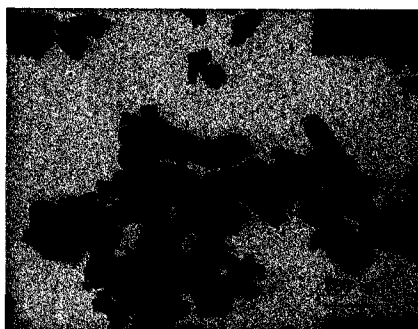
(a)



(b)



(c)



(d)

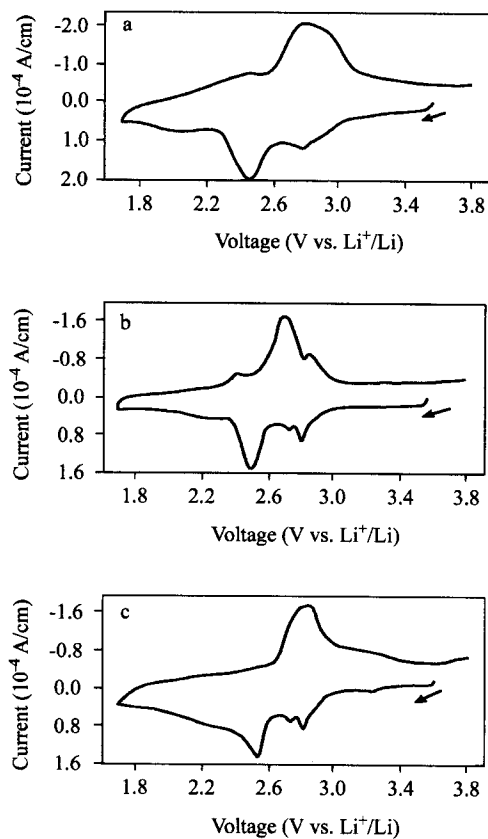
**Fig. 3** Transmission electron micrographs of  $\text{Li}_{1.2}\text{V}_3\text{O}_8$  dehydrated at different temperature: (a) heated to 250 °C; (b) heated to 300 °C; (c) heated to 350 °C; (d) heated to 400 °C.

The fact that  $\text{Li}_{1.2}\text{V}_3\text{O}_8$  gel could be obtained without overnight heating and stirring required in other low temperature methods<sup>8,9</sup> may be explained by the  $\text{V}_2\text{O}_5$  gel with an open structure being more reactable with  $\text{LiOH}$  than crystalline  $\text{V}_2\text{O}_5$ .<sup>17,18</sup> Though the mechanism of the formation of  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$  gel is not quite clear yet, we believe that many other vanadium-based compounds, besides  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$  could also be synthesized from  $\text{V}_2\text{O}_5$  gel easily. In fact, we have obtained  $\text{LT-Ag}_{1.2}\text{V}_3\text{O}_8$  using this method, and it will be reported elsewhere.

#### *Electrochemical property of LT- $\text{Li}_{1.2}\text{V}_3\text{O}_8$*

For checking the electrochemical performance of  $\text{LT-Li}_{1.2}\text{V}_3\text{O}_8$ , cyclic voltammetry and galvanostatic charge-discharge tests were carried out.

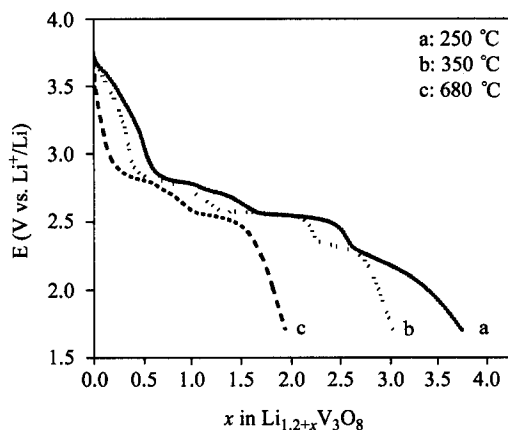
Fig. 4 shows the typical cyclic voltammograms of  $\text{LT-Li}_{1.2}\text{V}_3\text{O}_8$  and  $\text{HT-Li}_{1.2}\text{V}_3\text{O}_8$  at the scan rate of 0.05 mV/s. For  $\text{LT-Li}_{1.2}\text{V}_3\text{O}_8$  obtained at 250 °C, several broad peaks can be seen in Fig. 4a, instead of sharp peaks of  $\text{LT-Li}_{1.2}\text{V}_3\text{O}_8$  obtained at 350 °C and  $\text{HT-Li}_{1.2}\text{V}_3\text{O}_8$  in Fig. 4b and Fig. 4c respectively. It is tempting to explain this phenomenon by differences of their crystallinity. Fig. 4a represents a typical CV behavior of amorphous material. However, the broad anode peak in Fig. 4c is caused by the polarization



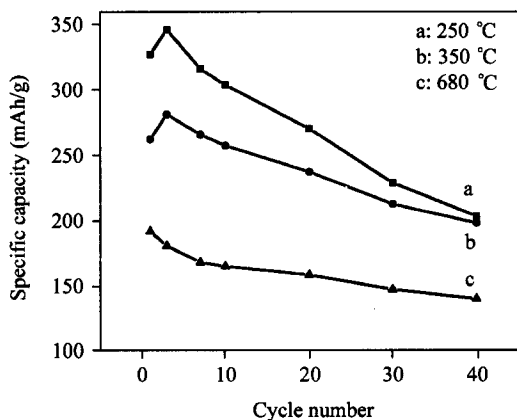
**Fig. 4** Typical cyclic voltammograms of  $\text{Li}_{1.2}\text{V}_3\text{O}_8$  at 0.05 mV/s, electrode active mass 5.0 mg: (a) heated to 250 °C; (b) heated to 350 °C; (c) conventional high temperature synthesis at 680 °C.

in the large particles as a consequence of high temperature treatment. The main cathodic peak potentials at 2.8 and 2.5 V are almost identical in each curve.

The third cycle discharge curves of these lithium vanadium oxides are illustrated in Fig. 5. The specific capacity of  $\text{LT-Li}_{1.2}\text{V}_3\text{O}_8$  obtained at 250 °C amounts 345 mAh/g ( $x = 3.75$  of  $\text{Li}_{1.2+x}\text{V}_3\text{O}_8$ ), which is much higher than 180 mAh/g ( $x = 1.95$  of  $\text{Li}_{1.2+x}\text{V}_3\text{O}_8$ ) of  $\text{HT-Li}_{1.2}\text{V}_3\text{O}_8$ . As also illustrated in Ref. 19 the material with lower crystallinity may have additional sites for lithium intercalation, which increases its specific capacity. Although the  $\text{LT-Li}_{1.2}\text{V}_3\text{O}_8$  prepared at 350 °C has only a specific capacity of 281 mAh/g lower than 345 mAh/g of the material made at 250 °C, this material shows better cyclic performance than 250 °C material. A capacity of 200 mAh/g is still maintained after 40 cycles as exhibited in Fig. 6.



**Fig. 5** Discharge curves on the third cycle of  $\text{Li}_{1.2}\text{V}_3\text{O}_8$  treated at different temperature (60 mA/g): (a) heated to 250 °C; (b) heated to 350 °C; (c) conventional high temperature synthesis at 680 °C.



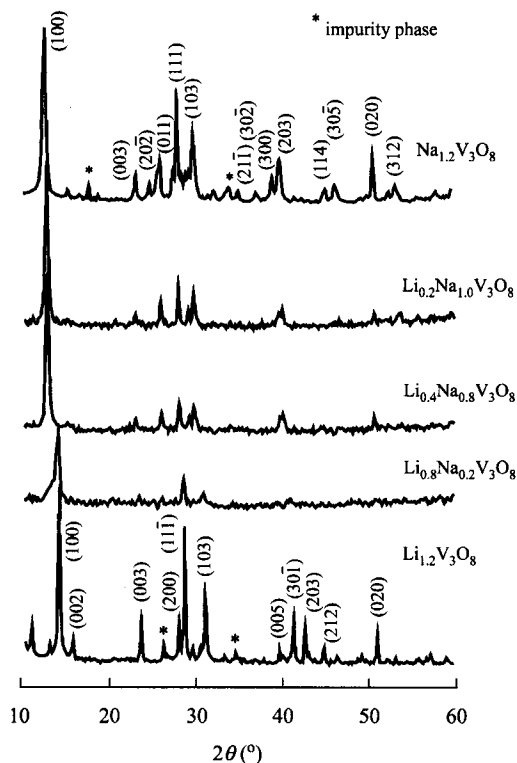
**Fig. 6** Changes in discharge capacity as a function of cycle number of  $\text{Li}_{1.2}\text{V}_3\text{O}_8$  (60 mA/g): (a) heated to 250 °C; (b) heated to 350 °C; (c) conventional high temperature synthesis at 680 °C.

It is worthwhile to note that water plays an important role in these materials obtained from  $\text{Li}_{1.2}\text{V}_3\text{O}_8$  gel. On the one hand, water molecules in  $\text{LT-Li}_{1.2}\text{V}_3\text{O}_8$  enlarge the gap between  $\text{V}_3\text{O}_8^-$  layers,<sup>7</sup> thus enhancing the mobility of  $\text{Li}^+$  ions

in it. On the other hand, water is one of the hindrances that has to be excluded from the nonaqueous lithium batteries for the sake of cyclability. Unfortunately, the higher temperature required for the complete removal of water would unavoidably bring about some crystallization of the products, which results in a decrease of capacity. Therefore the temperature of 350 °C was chosen for treatments of  $\text{LT-Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$ .

#### Characterization of $\text{LT-Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$

$\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$  was also synthesized easily by the method described above. The X-ray diffraction patterns of  $\text{LT-Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$  with varied  $y$  values are illustrated in Fig. 7. Although these materials were all treated at the temperature of 350 °C, they showed different degree of crystallinity.  $\text{Li}_{1.2}\text{V}_3\text{O}_8$  and  $\text{Na}_{1.2}\text{V}_3\text{O}_8$ , which have no foreign cations, exhibit higher crystallinity than those which have both  $\text{Li}^+$  and  $\text{Na}^+$  ions in  $\text{V}_3\text{O}_8^-$  layers. For  $\text{Li}_{1.2}\text{V}_3\text{O}_8$ ,  $\text{Li}^+$  ions occupy the octahedral sites in the zigzagged  $\text{V}_3\text{O}_8^-$  layers,<sup>20</sup> but for  $\text{Na}_{1.2}\text{V}_3\text{O}_8$ ,  $\text{Na}^+$  ions are situated at octahedral and tetrahedral sites between the layers.<sup>21</sup> In the case of  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$ ,  $\text{Li}^+$  ions function as competitive opponents to  $\text{Na}^+$  ions relying on their smaller ionic radii and higher mobility by occupying more octahedral sites. This results in some distortion of the regular arrangement of atoms as in  $\text{Li}_{1.2}\text{V}_3\text{O}_8$  or  $\text{Na}_{1.2}\text{V}_3\text{O}_8$ ,<sup>21</sup> and some reduction of the long-range order. The main peak, namely the (100) diffraction peak is the strongest one, which lies between 13° and 14° in each pattern.



**Fig. 7** XRD patterns of  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$  prepared at 350 °C.

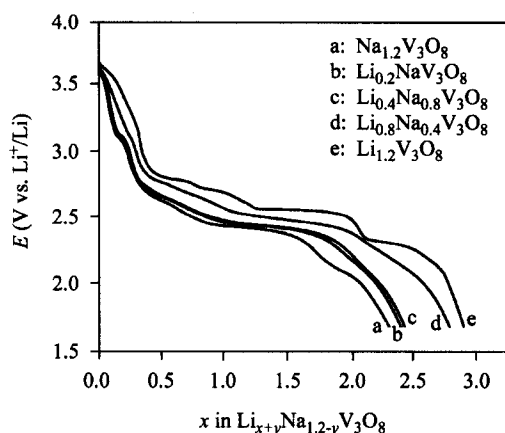
As shown in Table 1, the  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$  with higher Na content has larger interlayer distance. The  $d_{100}$  increases from 0.6228 to 0.7029 nm as Li/Na ratio dropping from  $\text{Li}_{1.2}\text{V}_3\text{O}_8$  to  $\text{Na}_{1.2}\text{V}_3\text{O}_8$ . It is assumed that positively charged  $\text{Li}^+$  or  $\text{Na}^+$  ions act as pillars holding the  $\text{V}_3\text{O}_8^-$  layers electrostatically. With the ionic radii of 0.10 nm larger than 0.07 nm of  $\text{Li}^+$ ,  $\text{Na}^+$  ions set the  $\text{V}_3\text{O}_8^-$  layers more apart.

**Table 1** Changes in  $d_{100}$  values as a function of  $y$  in  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$

$y$ in $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$	0	0.4	0.8	1.0	1.2
$d_{100}$ ( $10^{-1}$ nm)	6.228	6.328	6.884	6.9	7.029

### Electrochemical tests of LT- $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$

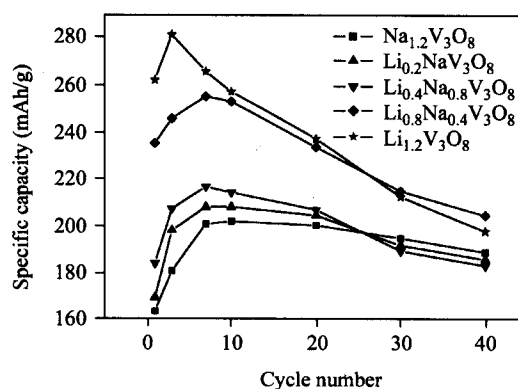
Fig. 8 depicts the typical discharge curves of LT- $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$  obtained at a current rate of 60 mA/g. The amount of inserted lithium decreases with the increase of the content of  $\text{Na}^+$  in  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$ . Maybe the electrostatic interaction between  $\text{Li}^+$  and  $\text{Na}^+$  ions could account for this. It is assumed that  $\text{Na}^+$  ions are stabilized in  $\text{V}_3\text{O}_8^-$  layers while  $\text{Li}^+$  ions shuttle in the host of  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$ . Consequently there is some repulsion between these two kinds of cations, which results in an obstruction in lithium transportation. As far as the discharge voltages are concerned, the same rule goes. That is to say,  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$  with higher  $\text{Na}^+$  content has lower discharge voltage. It is due to the different site energy of intercalated lithium atoms. As seen in Table 1, since the presence of  $\text{Na}^+$  ions enlarge the interlayer distance between  $\text{V}_3\text{O}_8^-$  layers, the tetrahedral sites available for lithium accommodation stand lower site energy.



**Fig. 8** Typical discharge curves of  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$  prepared at 350 °C (60 mA/g).

Fig. 9 shows the discharge capacities of LT- $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$  as a function of cycle number. Although  $\text{Li}_{1.2}\text{V}_3\text{O}_8$  has the highest specific capacity, it endures the most rapid capacity fading from 281 mAh/g ( $x = 2.95$  of  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$ ) dropping to 198 mAh/g ( $x = 2.0$ ). With the  $\text{Na}^+$  content increasing,  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$  shows better cyclability.

However, too much  $\text{Li}^+$  ions substituted by  $\text{Na}^+$  ions will badly sacrifice its capacity.



**Fig. 9** Changes in discharge capacity as a function of cycle number of  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$  (60 mA/g).

A peculiar feature for these low temperature products is also seen in Fig. 9, *i. e.*, the discharge capacity climbs to a climax in the initial cycles before capacity fading. This phenomenon was also observed for other low temperature products.<sup>9,22</sup> There is no doubt owing to the structural difference from the high temperature products. During the initial cycles, by shuttling in the channels  $\text{Li}^+$  ions probably cause a modification of the host structure so that they diffuse more smoothly. Further study on the detailed mechanism is still in progress in our laboratory.

### Conclusion

$\text{Li}_{1.2}\text{V}_3\text{O}_8$  and its analogs  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$  have been successfully synthesized from  $\text{V}_2\text{O}_5$  gel at relatively low temperature (150–350 °C). The products thus prepared possess smaller particle size, lower crystallinity, and show better electrochemical performances than conventional high temperature (680 °C) products. The new low temperature synthesis route could vigorously enhance the efficiency on production of  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$ . The electrochemical performance of  $\text{Li}_{1.2}\text{V}_3\text{O}_8$  depends much on its heating temperature required for water removal.  $\text{Li}_{1.2}\text{V}_3\text{O}_8$  treated at 250 °C exhibits the highest discharge capacity of 350 mAh/g, but  $\text{Li}_{1.2}\text{V}_3\text{O}_8$  treated at 350 °C shows better cycle performance than the 250 °C material and higher capacity than the high temperature product.

Partial substitution of Li by Na influences the electrochemical performance of  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$  greatly. With the increase of Na/Li ratio, the cyclability of  $\text{Li}_{1.2-y}\text{Na}_y\text{V}_3\text{O}_8$  is improved indeed, but its discharge potentials and specific capacity are all lowered.

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