Quantitative Analysis of Large Voltage Hysteresis of Lithium Excess Materials by Backstitch Charge and Discharge Method

Kingo Ariyoshi, Takayuki Inoue, and Yusuke Yamada

Department of Applied Chemistry and Bioengineering, Graduate School of Engineering, Osaka City University, Sumiyoshi-ku, Osaka 558-8585, Japan

Lithium-excess (LEX) materials (LiMO2–Li3MnO2; M = Co, Ni, etc.) are attractive as potential positive electrodes of high-capacity lithium-ion batteries, however, large voltage hysteresis of LEX materials in charge and discharge disturbs real application. Thus, the large voltage hysteresis was investigated by a novel electrochemical method termed as a “backstitch charge and discharge” (backstitch CD) method, in which unsymmetrical charge and discharge with a small capacity were continuously repeated. The backstitch CD method was applied to Li[Li1/3Ti5/3]O4 (Li4Ti5O12), Li[Li0.5Co0.5Mn1.5]O2 (0.5Li2CO3–0.5Li2MnO3) known as an LEX material for the first time. Li[Li1/3Ti5/3]O4 and Li[Li0.5Co0.5Mn1.5]O2 showed different reversible potentials during the backstitch CD processes in spite of symmetrical polarization behavior at each process. The voltage hysteresis in Li[Li1/3Ti5/3]O4 resulted from electrochemically reversible but different reactions occurring during charging and discharging processes. Contributions of overpotential and difference in reversible potential to the voltage hysteresis can be evaluated quantitatively by the backstitch CD method.

© The Author(s) 2018. Published by ECS. This is an open access article distributed under the terms of the Creative Commons Attribution 4.0 License (CC BY, http://creativecommons.org/licenses/by/4.0/), which permits unrestricted reuse of the work in any medium, provided the original work is properly cited. DOI: 10.1149/2.0701811jes
Results and Discussion

Electrochemical behavior of Li[Li_{1/5}Co_{2/5}Mn_{2/5}]O_2.—XRD examination revealed that the Li[Li_{1/5}Co_{2/5}Mn_{2/5}]O_2 prepared in this study has a layered structure with a hexagonal lattice (a = 2.831 Å and c = 14.18 Å). The lattice volume per a formula unit (V_{lattice}/Z) of Li[Li_{1/5}Co_{2/5}Mn_{2/5}]O_2 was 65.6 Å^3, which is close to the average value of those of LiCoO_2 (64.5 Å^3) and Li_2MnO_3 (66.7 Å^3). Very weak superlattice lines observed in the 2θ range from 25 to 35 degrees resulted from cation ordering of Li and transition metal ions (Co and Mn ions) in transition layers. The increase of cobalt contents resulted in weaker superlattice lines, suggesting that the crystal symmetry changes from monoclinic to hexagonal lattice. These structural features evidenced that Li[Li_{1/5}Co_{2/5}Mn_{2/5}]O_2 was a Li-excess (LEX) material derived from a solid solution between LiCoO_2 and Li_2MnO_3.

Charge and discharge curves of an LTO/Li[Li_{1/5}Co_{2/5}Mn_{2/5}]O_2 cell for 30-cycle tests are shown in Figure 1. The cell was operated at a rate of 0.25 mA cm^-2 in the voltage range of 0.5–3.3 V vs. LTO at 25°C. The left vertical axis of Figure 1 indicates the electrochemical behavior of the Li[Li_{1/5}Co_{2/5}Mn_{2/5}]O_2 electrode from the electrode potential of Li[Li_{1/5}Co_{2/5}Mn_{2/5}]O_2 against a lithium metal electrode (+1.55 V). The electrochemical behavior of the Li[Li_{1/5}Co_{2/5}Mn_{2/5}]O_2 showed unique features of LEX materials, i.e., the long voltage plateau at 4.5 V at the initial charge, the large voltage difference between charge and discharge, and the sudden decrease in capacities for both charge and discharge at later cycles. The large capacity, ca. 300 mAh g^-1, at the first charge is larger than the expected value accompanied by the oxidation of Co^{3+} to Co^{4+} for conventional lithium insertion materials. Capacities gradually decreased for both charge and discharge at subsequent cycles from 200 mAh g^-1 at the 2nd cycle to 180 mAh g^-1 at 30th cycle. Charge capacity above 4.0 V and discharge capacity above 3.5 V decreased at later cycles, where the voltage difference between charge and discharge was larger than 0.5 V. The operating voltage on charge linearly increases from 3.5 to 4.5 V while discharging consists of two sigmoidal curves around 4.0 and 3.3 V. Discharge voltage went down to lower than 3 V at 30th cycle from 3.5 V at the 1st cycle. The large voltage hysteresis observed in charge and discharge curves of Li[Li_{1/5}Co_{2/5}Mn_{2/5}]O_2 is characteristic for LEX materials. Such large voltage hysteresis has never been reported for conventional lithium insertion materials, i.e., LiMnO_2 having a layered structure, LiMPO_4 having a spinel structure and LiMPO_4 having a forsterite structure (M = 3d transition metals). However, the capacity of Li[Li_{1/5}Co_{2/5}Mn_{2/5}]O_2 retained with high coulombic efficiency during the cycles indicates that the lithium-insertion reaction could proceed in spite of the large voltage hysteresis.

Polarization measurements of the Li[Li_{1/5}Co_{2/5}Mn_{2/5}]O_2 electrode.—Open-circuit voltage (OCV) measurements were carried out for an LTO/Li[Li_{1/5}Co_{2/5}Mn_{2/5}]O_2 cell to scrutinize the voltage hysteresis (Figure 2). OCVs of the cell after charged or discharged to a desired capacity were determined by leaving under open-circuit conditions for 10 h. OCVs of the cell were low and high compared with operating voltages (closed-circuit voltage; CCV) during charge and discharge, respectively. Polarization defined as a voltage difference between OCV and CCV during charge was smaller than that during discharge. The polarization of 100 to 300 mV during charge depends on state of charge, which was smaller than that during discharge, ca. 400 mV. OCVs measured during charge was not the same as those during discharge over the entire range. The maximum difference in OCVs between charge and discharge was ca. 300 mV at a certain capacity ranging from 50 to 130 mAh g^-1. The OCVs during charge were always smaller than that during discharge even when the cell was kept under the open-circuit condition for 1 month. Thus, the difference in OCVs during charge and discharge induced the large voltage hysteresis of Li[Li_{1/5}Co_{2/5}Mn_{2/5}]O_2 as well as other LEX materials.31-35 Polarization measurements carried out at the same state of charge for both charge and discharge can elucidate the difference of OCVs during charge and discharge (Figure 3). Polarization curves measured for the LTO/Li[Li_{1/5}Co_{2/5}Mn_{2/5}]O_2 cell are also shown in
Polarization measurements were performed for the LTO/Li\[Li_{1/5}Co_{2/5}Mn_{2/5}\]O\(_2\) cell at the same charge capacity of 100 mAh g\(^{-1}\). Red and blue circles indicate OCV of the cell after charging and discharging processes, respectively. Charge and discharge curves obtained without pausing are indicated in black dotted line. (a, b) Time course of polarization voltage of the LTO/Li\[Li_{1/5}Co_{2/5}Mn_{2/5}\]O\(_2\) cell measured at the same charge capacity of 100 mAh g\(^{-1}\) after (a) charging and (b) discharging processes, respectively. For polarization measurements, a constant current density chosen from 0.05, 0.10, 0.25, 0.5, 1.0, and 2.5 mA cm\(^{-2}\) was applied to the cell for 10 s. After each measurement, the cell was rested for (a) 1 h and (b) 1.5 h.

Figures 3a and 3b. The chemical composition or the lithium content of Li\(_{1-x}\)Li\(_{0.5}Co_{0.25}Mn_{0.25}\)O\(_2\) was expected to be the same in both of the states although large voltage plateau associated with oxygen evolution at the first charge disturbs rigorous determination of the lithium content of the material. Polarization measurements were performed for the cell charged (oxidized) or discharged (reduced) with applied at several current densities for a short period (10 s). The polarization measurements at charge (Figure 3a) indicated that the applying current to the cell induced the sudden change of cell voltage owing to the activation and resistance overvoltage. The slight change in the cell voltage during oxidation or reduction reaction results from time-dependent processes, such as lithium-ion diffusion in solid matrix and/or liquid electrolyte. The cell voltage went back to 4.0 V quickly by turning off the current. The positive and negative current densities indicate anodic (oxidation reaction) and cathodic (reduction reaction) currents, respectively. The polarization curve for charging process was almost linear (Figure 4a), while that for discharging process was not a straight line (Figure 4b). The resistance of the cell was determined to be ca. 70 Ω cm\(^2\) from the slope of the polarization curve for charging process. The larger slope of the polarization curve for discharging process suggests that the resistance of the electrode was larger than that for charging process. This agrees well with the polarization during charging and discharging processes evaluated from OCV measurements shown in Figure 2. Both polarization curves on charging and discharging processes are symmetric around the OCVs but not the same, suggesting that the electrochemically reversible reaction during charging process differs from that during discharging process. Consequently, OCVs on charging and discharging processes can be defined as reversible electrode potentials of the Li\[Li_{1/5}Co_{2/5}Mn_{2/5}\]O\(_2\), hence the difference between polarization voltage and OCV can be defined as overpotential. The polarization measurements revealed large voltage hysteresis of Li\[Li_{1/5}Co_{2/5}Mn_{2/5}\]O\(_2\) consisting of two kinds of voltage difference; one is overpotential determined by a slope of polarization curves and the other is a reversible potential difference.

The former is related to kinetics of the electrochemical reaction of the Li\[Li_{1/5}Co_{2/5}Mn_{2/5}\]O\(_2\) electrode, because overpotential depends on current density. The latter is related to thermodynamics of electrochemical reaction of Li\[Li_{1/5}Co_{2/5}Mn_{2/5}\]O\(_2\), because reversible electrode potentials correspond to the free energy change of the reactions. These results indicate that minimizing the difference in reversible potentials in addition to reducing the overpotential is important to reduce or diminish voltage hysteresis in LEX materials.
Two backstitch CD curves on charging and discharging processes are depicted in Figure 7. The two curves (red for charging process and blue for discharging process) were not the same over the entire range, indicating that different kinds of electrochemical reactions of the Li[Li1/5Co2/5Mn2/5]O2 material proceeded on charging and discharging processes. Overpotential of the Li[Li1/5Co2/5Mn2/5]O2 electrode at every state of charge can be estimated from the voltage difference between oxidation and reduction segments, or from vertical separation in the backstitch CD curves. Reversible electrode potentials and overpotential, however, only the backstitch method can provide voltage profiles during charging and discharging processes, separately, clearly indicating that the large voltage hysteresis of LEX materials results from different electrochemical reactions during charging and discharging processes.

Backstitch CD curves of Li[Li1/5Co2/5Mn2/5]O2 electrodes are quite different from continuous charge and discharge curves at low current density. The gap between the two voltage profiles is caused by a period of time on oxidation and reduction segments, i.e., repeated charge and discharge cycling with a small capacity range for the backstitch method versus continuous charge and discharge cycling with full capacity. Backstitch CD tests with changing oxidation and discharging processes during charging or discharging process, the cell was charged at 0.25 mA cm\(^{-2}\) for 10 (or 5) mA h g\(^{-1}\) at oxidation segments (red line) and discharged at −0.25 mA cm\(^{-2}\) for 5 (or 10) mA h g\(^{-1}\) at reduction segments (blue). Charge-end and discharge-end voltages were 3.3 and 0.5 V vs. LTO, respectively. The cell was cycled for 20 times in advance. Electrode weight and thickness of positive electrode are 25.9 mg and 73 \(\mu\)m, respectively.

Figure 6. Charge and discharge curves obtained by the backstitch CD method for an LTO/Li[Li1/5Co2/5Mn2/5]O2 cell during (a) charging and (b) discharging processes.

Figure 7. Combined backstitch CD curves obtained by backstitch charge and discharge test of the LTO/Li[Li1/5Co2/5Mn2/5]O2 cell during (a) charging and (b) discharging processes.
The reaction mechanism of Li[Li\(_{1/5}\)Co\(_{2/5}\)Mn\(_{2/5}\)]O\(_2\). The backstitch CD roughly estimate overpotentials and reversible potentials for studying while the small broad peak at the same voltage was observed during large reduction peak at 3.4 V was observed during discharging process, charging process was larger than that during discharging process. The oxidation peak above 4.0 V during charging and discharging processes independently (Figure 9). The clarification correspondence between oxidation and reduction peaks during charging and discharging processes almost the same for the backstitch CD curves measured for large segment capacities can dramatically changed voltage profiles. Similar backstitch CD curves obtained for the segment capacities greater than 10 mAh g\(^{-1}\). Red and blue lines indicate curves during oxidation and reduction segments, respectively.

Quantitative analysis on large voltage hysteresis of the Li[Li\(_{1/5}\)Co\(_{2/5}\)Mn\(_{2/5}\)]O\(_2\) electrode from backstitch charge and discharge curves.—Four characteristic potentials determined by the backstitch CD method, oxidation and reduction potentials on charge and discharge segments (\(E_{\text{Ox,Cha}}, E_{\text{Red,Cha}}, E_{\text{Ox,Dis}},\) and \(E_{\text{Red,Dis}}\)), were used for analyzing the voltage hysteresis in the Li[Li\(_{1/5}\)Co\(_{2/5}\)Mn\(_{2/5}\)]O\(_2\) electrode. Figure 10 shows the four characteristic potentials obtained from the backstitch CD curves with various segment capacities in Figure 8. \(E_{\text{Ox,Cha}}\) (closed red circles) and \(E_{\text{Red,Dis}}\) (open blue circles) shifted toward higher and lower voltages, respectively, with increasing the segment capacities, on the other hand, \(E_{\text{Ox,Cha}}\) (open red circles) and \(E_{\text{Red,Dis}}\) (closed blue circles) showed no significant change regardless of segment capacities. Average values of four characteristic potentials were plotted as a function of the segment capacities (Figure 11). Oxidation potentials, \(E_{\text{Ox,Cha}}\) and \(E_{\text{Ox,Dis}}\) (open circles), increased with increasing the segment capacities, on the other hand, reduction potentials, \(E_{\text{Red,Cha}}\) and \(E_{\text{Red,Dis}}\) (closed circles), decreased. The change in the potentials was partially due to a limitation of capacity region measured for the potentials, i.e. \(E_{\text{Ox}}\) at lower capacity region and \(E_{\text{Red}}\) at higher capacity region cannot be measured due to large segment capacities. As shown in Figure 11, average potentials extrapolated to 0 mAh g\(^{-1}\) of segment capacity correspond to oxidation and reduction potentials obtained from polarization measurements with very small capacity. Therefore, reversible potentials and overpotential of the Li[Li\(_{1/5}\)Co\(_{2/5}\)Mn\(_{2/5}\)]O\(_2\) electrode can be obtained by basic arithmetic operation of four characteristic voltages when segment capacity approaches to be 0 mAh g\(^{-1}\). Overpotential on both oxidation and reduction reaction corresponds to the subtraction of a reduction

![Figure 8](image1.png)

**Figure 8.** Backstitch CD curves of LTO/Li[Li\(_{1/5}\)Co\(_{2/5}\)Mn\(_{2/5}\)]O\(_2\) cells with changing the capacities of oxidation and reduction segments; (a) 4 mAh g\(^{-1}\) and 2 mAh g\(^{-1}\), (b) 10 mAh g\(^{-1}\) and 5 mAh g\(^{-1}\), (c) 30 mAh g\(^{-1}\) and 25 mAh g\(^{-1}\), and (d) 60 mAh g\(^{-1}\) and 55 mAh g\(^{-1}\). Red and blue lines indicate voltage profiles during charging and discharging processes, respectively.

![Figure 9](image2.png)

**Figure 9.** Differential chronopotentiograms (dQ/dE plots) calculated from the Backstitch CD curves of a LTO/Li[Li\(_{1/5}\)Co\(_{2/5}\)Mn\(_{2/5}\)]O\(_2\) cell during (a) charging and (b) discharging processes with capacities of 60 mAh g\(^{-1}\) on oxidation segments and 55 mAh g\(^{-1}\) on reduction segments (Figure 8d). Red and blue lines indicate curves during oxidation and reduction segments, respectively.
Figure 10. Four characteristic voltages obtained from backstitch CD curves shown in Figure 8 [(a) 4 mAh g\(^{-1}\) and 2 mAh g\(^{-1}\), (b) 10 mAh g\(^{-1}\) and 5 mAh g\(^{-1}\), (c) 30 mAh g\(^{-1}\) and 25 mAh g\(^{-1}\), and (d) 60 mAh g\(^{-1}\) and 55 mAh g\(^{-1}\)]. Open and close circles indicate the cell voltages at the end of oxidation and reduction segments, \(E_{\text{ox}}\) and \(E_{\text{red}}\), respectively. Red and blue circles indicate cell voltages during charging and discharging processes, \(E_{\text{cha}}\) and \(E_{\text{dis}}\), respectively.

Figure 11. Four characteristic potentials of Li[Li\(_{1/5}\)Co\(_{2/5}\)Mn\(_{2/5}\)]O\(_2\) as a function of segment capacity. Average potentials on oxidation and reduction segments during charging and discharging processes are labelled as \(E_{\text{ox,cha}}\), \(E_{\text{red,cha}}\), \(E_{\text{ox,dis}}\), and \(E_{\text{red,dis}}\).

Figure 12. (a) The difference between oxidation and reduction potentials on charging process, \(\Delta E_{\text{cha}} = E_{\text{ox,cha}} - E_{\text{red,cha}}\), and discharging processes, \(\Delta E_{\text{dis}} = E_{\text{ox,dis}} - E_{\text{red,dis}}\). The average overpotential during charging and discharging processes at 0 mAh g\(^{-1}\) of the segment capacity corresponds average overpotential during charging and discharging processes. (b) The difference in average reversible potentials between charging and discharging processes as a function of segment capacity, \(\Delta E_{\text{rev}} = E_{\text{rev,cha}} - E_{\text{rev,dis}}\). The average reversible potentials during charging and discharging processes are calculated by the following equations; \(E_{\text{rev,cha}} = (E_{\text{ox,cha}} + E_{\text{red,cha}})/2\) for charging process and \(E_{\text{rev,dis}} = (E_{\text{ox,dis}} + E_{\text{red,dis}})/2\) for discharging process.
reactions were kinetically reversible. The large voltage hysteresis of the Li[Li$_{1/5}$Co$_{2/5}$Mn$_{2/5}$]O$_2$ electrode resulted from two potential differences, reversible electrode potential differences and overpotential. Thus, the analysis on the backstitch CD curves allows to evaluate the contributions of the reversible electrode potential difference ($\Delta E_{rev} = 400$ mV) and the overpotentials (200 mV and 400 mV for charging and discharging processes, respectively) to voltage hysteresis quantitatively.

Conclusions

Li[Li$_{1/5}$Co$_{2/5}$Mn$_{2/5}$]O$_2$ known as a lithium-excess material showed large voltage hysteresis in its charge and discharge curves, more than 500 mV, without significant capacity fading during 30 cycles. The polarization measurements revealed that Li[Li$_{1/5}$Co$_{2/5}$Mn$_{2/5}$]O$_2$ exhibited that electrochemical reactions of the material were not the same between charging and discharging processes, causing two different irreversible electrode potentials at the same state of charges. The backstitch charge and discharge method, in which unsymmetrical charge and discharge cycles with small capacity were continuously repeated, was able to provide two important electrochemical parameters, i.e., reversible potential and overpotential, simultaneously. The difference in reversible potentials between charging and discharging processes was as large as 400 mV, consequently, electrochemical reaction of the electrode materials showing large voltage hysteresis is necessary to progress thermodynamically rather than kinetically in order to reduce or diminish voltage hysteresis. Thus, it is manifested that the large voltage hysteresis is caused by the difference in reversible electrode potentials during charging and discharging process and polarization.

The backstitch charge and discharge method disclosed here would be a powerful tool to investigate electrochemical reactions of electrode materials with large voltage hysteresis in their charge and discharge curves, because difference in reversible electrode potentials during charging and discharging processes is thought to be the main reason for large voltage hysteresis. This method is applicable to some other electrode materials for high-capacity lithium-ion batteries with large voltage hysteresis, such as anionic redox materials, the lithium-alloy electrodes, the conversion electrode, etc. Reversible electrode potentials corresponding to free energy and overpotential corresponding to kinetics of an electrochemical reaction will provide useful insights to understand reaction mechanism.

ORCID

Kingo Ariyoshi @ https://orcid.org/0000-0002-6784-6639

References

1. E. M. Erickson, F. Schipper, T. R. Penki, J.-Y. Shin, C. Erk, F.-F. Chesneau, B. Markovsky, and D. Aurbach, J. Electrochem. Soc., 164, A6341 (2017).
2. G. Assat and J.-M. Tarascon, Nat. Energy, 3, 373 (2018).
3. A. Manthiram, J. C. Knight, S.-T. Myung, S.-M. Oh, and Y.-K. Sun, Adv. Energy Mater., 6, 1501010 (2016).
4. Z. Lu and J. R. Dahn, J. Electrochem. Soc., 150, A1044 (2003).
5. M. Tabuchi, Y. Nabeshima, M. Shilamp, K. Ado, H. Kagayama, and K. Tatsumi, J. Electrochem. Soc., 154, A638 (2007).
6. Y. Sun, Y. Shiosaki, Y. Xia, and H. Noguchi, J. Power Sources, 159, 1353 (2006).
7. Z. Lu, L. Y. Beaulieu, R. A. Donabarger, C. L. Thomas, and J. R. Dahn, J. Electrochem. Soc., 149, A778 (2002).
8. T. Ohzuku, M. Nagayama, K. Tsuji, and K. Ariyoshi, J. Mater. Chem., 21, 10179 (2011).
9. C. S. Johnson, N. Li, C. Lerief, J. T. Vaughan, and M. M. Thackeray, Chem. Mater., 20, 6995 (2008).
10. M. Sathiya, G. Rousse, K. Ramesha, C. P. Laisa, H. Vezin, M. T. Sougrati, M.-L. Doublet, D. Foix, D. Gonbeau, W. Walker, A. S. Prakash, M. Ben Hassine, L. DuPont, and J.-M. Tarascon, Nat. Mater., 12, 827 (2013).
11. N. Yabuuchi, M. Takeuchi, M. Nakayama, H. Shibata, M. Ogawa, K. Nakayama, T. Ohba, D. Endo, T. Ozaki, T. Inamasu, K. Sato, and S. Komaba, PNAS, 112, 7650 (2015).
12. N. Yabuuchi, M. Nakayama, M. Takeuchi, S. Komaba, Y. Hashimoto, T. Mukai, H. Shibata, K. Sato, Y. Kobayashi, A. Nakao, M. Yonemura, K. Yamakawa, K. Mitsuhashi, and T. Ohba, Nat. Commun., 7, 13814 (2016).
13. N. Yabuuchi, T. Tahara, S. Komaba, S. Kitada, and Y. Kajiya, Chem. Mater., 28, 416 (2016).
14. N. Yabuuchi, Chem. Lett., 48, 412 (2017) and cited references therein.
15. Z. Lu and J. R. Dahn, J. Electrochem. Soc., 149, A815 (2002).
16. A. R. Armstrong, M. Holzapfel, P. Novak, C. S. Johnson, S. Kang, M. M. Thackeray, and P. G. Bruce, J. Am. Chem. Soc., 281, 8694 (2006).
17. A. Ito, K. Shoda, Y. Sato, M. Hatano, H. Horie, and Y. Ohsawa, J. Power Sources, 196, 4785 (2011).
18. C. R. Fell, D. Qian, K. J. Carroll, M. Chi, and J. L. Jones, Chem. Mater., 25, 1621 (2013).
19. L. Simonin, J. Colin, V. Ranieri, E. Casevet, J. Martin, C. Bourbon, C. Baetlitz, P. Strobel, L. Daniel, and S. Patoux, J. Mater. Chem., 22, 11316 (2012).
20. J. R. Croy, K. G. Gallagher, M. Balasubramanian, Z. Chen, Y. Ren, D. Kim, S.-H. Kang, D. W. Dees, and M. M. Thackeray, J. Phys. Chem. C, 117, 6525 (2013).
21. A. Ito, Y. Sato, T. Sanada, M. Hatano, H. Horie, and Y. Ohsawa, J. Power Sources, 196, 6828 (2011).
22. M. Oishi, T. Fujimoto, Y. Takahashi, Y. Irikasa, A. Kawamura, T. Ina, H. Yamashige, D. Takamatsu, K. Sato, H. Murayama, H. Tanida, H. Arai, H. Ishii, C. Yogi, I. Watanabe, T. Ohba, A. Mineshige, Y. Uchimoto, and Z. Ogumi and, J. Power Sources, 222, 45 (2013).
23. G. Assata, C. Delacourt, A. D. A. Cortie, and J.-M. Tarascon, J. Electrochem. Soc., 163, A2965 (2016).
24. M. Kasai, S. Nishihara, A. Gunji, H. Konishi, X. Feng, S. Furutsuki, and S. Takahashi, Electrochim. Acta, 146, 79 (2014).
25. H. Konishi, T. Hirano, A. Gunji, D. Takamatsu, X. Feng, and S. Furutsuki, J. Power Sources, 298, 144 (2015).
26. J. G. Wen, J. Bareno, C. H. Lei, S. H. Kang, M. Balasubramanian, I. P Petrov, and D. P. Abraham, Solid State Ionics, 182, 98 (2011).
27. J. Bareno, M. Balasubramanian, S. H. Kang, J. G. Wen, C. H. Lei, S. V. Pol, I. Petrov, and D. P. Abraham, Chem. Mater., 23, 2039 (2011).
28. T. Ohzuku and K. Sawat, Denki Kagaku, 64, 1000 (1996).
29. K. Nakura, Y. Ohsumi, M. Imazaki, K. Ariyoshi, and T. Ohzuku, J. Electrochem. Soc., 158, A1243 (2013).
30. T. Ohzuku and A. Ueda, J. Electrochem. Soc., 141, 2972 (1994).
31. P. Strobel and B. Lambert-Andon, J. Solid State Chem., 75, 90 (1988).
32. T. Ohzuku, A. Ueda, and N. Yamamoto, J. Electrochem. Soc., 142, 1431 (1995).
33. B. Lu, Y. Song, Q. Zhang, J. Pan, Y.-T. Cheng, and J. Zhang, Phys. Chem. Chem. Phys., 18, 4721 (2016).
34. L. Li, R. Jacobs, P. Gao, L. Gan, F. Wang, D. Morgan, and S. Jin, J. Am. Chem. Soc., 138, 2838 (2016).
35. R. Khatib, A.-L. Dalvernny, M. Saubanère, M. Gaborcek, and M.-L. Doublet, J. Phys. Chem. C, 117, 837 (2013).

Journal of The Electrochemical Society, 165 (11) A2675-A2681 (2018)