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A study on thermal performance of batteries using thermal imaging and infrared radiation

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ABSTRACT

This study attempted to improve the performance of pouch-type lithium iron phosphate battery ($LiFePO_4$) through analysis on its degradation mechanism at a high rate (10 C) for the purpose of observing resistance and electrochemical changes in each material when a battery was manufactured considering the low electrical conductivity and of lithium iron phosphate and properties of cathode materials. For this, the life and safety of lithium batteries are evaluated after forming dendrites through the reduction of lithium at the negative electrode (graphite) as resistance in $LiFePO_4$. The components of $LiFePO_4$, which generate this kind of resistance includes tab, electrolytes, cathode active materials, anode active materials, binders and conductive materials. The main cathode (lithium-ion phosphate) and anode (natural graphite) materials were fabricated in 90% and 96% respectively, using conductive materials and binders. For a case, a 20 Ah Al pouch was fabricated. A full cell was fabricated with the best materials and components through analysis on resistance characteristic. Then, $LiFePO_4$ was thermally safer with a long lifespan than the conventional high-rate output. For analysis on materials, in addition, basic material analysis was performed through impedance, X-ray diffraction (XRD), X-Scan and field emission scanning electron (FESEM). After tracing heat generated within the battery using infrared radiation (IR), the degree of degradation was examined. Then, the degradation rates of lithium batteries and reliability of measurements were comparatively assessed. When analyzed with an infrared camera, temperature rapidly rose up to over 80 °C during charge and discharge. A battery was fabricated using an industrial engineering method which can secure internal resistance-lowering slurry and coating dispersion processes and reduce resistance in the binder and tab joint. As a result, it was able to substitute conventional $LiFePO_4$ with high internal resistance, disperse heat inside the cell and increase its lifespan.

Introduction

Since the beginning of the new millennium, mobile device market (ex: mobile phone, camera, laptop computer and power tools) has explosively grown thanks to the widespread use of lithium-ion batteries. Recently, lithium-ion batteries have expanded to new fields such as automated guided vehicle (AGV), robot and Internet of Things (IoT). In emergency power and energy demand management such as energy storage system (ESS) [1–3] and uninterruptible power supply (UPS) and green car market (X-eV) as well, lithium-ion batteries [4–6] have become more important these days.

The lithium-ion battery with high energy density and long lifespan was a lithium cobalt oxide ($LiCoO_2$) battery in the beginning. Based on high energy density, it was applied to IT devices. However, there was a strong demand for performance improvement because of safety such as a risk of battery explosion and output limitations. For higher safety and greater performances, batteries have evolved through the development of diverse cathode materials such as lithium nickel oxide, spinel lithium manganese oxide and lithium iron phosphate. However, cobalt and nickel cathode materials have the following problems: structural instability, high material costs and rapid drop in capacity in high-temperature environment (manganese cathode materials).

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$LiFePO_4$ was first proposed by Goodenough's Group in 1997 and deemed as a new candidate for a cathode material. It had relatively big theory capacity (170 mAh/g) with high safety and great price competitiveness. Due to low electrical conductivity and poor energy density, however, $LiFePO_4$ was not used as a commercial active material.

Some studies overcame the low electrical conductivity of $LiFePO_4$ through carbon coating, doping transition metal ion and decrease in particle sizes. According to a previous study, 1 wt% of $LiFePO_4$ reveals almost 160 mA/g at 80 °C in terms of carbon coating capacity. Yamada Group displayed relatively stable electrochemical capability by reducing particle sizes at room temperature. Huang Group mixed fine carbon particles with precursors prior to metallurgy in the carbon-coated $LiFePO_4$. This kind of composition reveals improved energy density and higher durability at room temperature. Even so, electrochemically inert carbon is the primary cause of the loss of energy density in cathode active materials. Recently, Peng et al. has studied on the thermal safety of lithium-ion batteries with various cathode materials: a numerical study. A three-dimensional thermal model describing oven abuse processes of lithium-ion batteries was established to study the thermal stability and thermal safety of cathode materials. And the critical oven temperature to trigger thermal runaway is obtained [7]. Dey et al. researched the real-time thermals fault diagnosis of lithium-ion batteries, and a diagnostic algorithm was presented that diagnoses thermal faults in lithium-ion batteries in this study [8]. Therefore, a lot of improvements for better lithium ion batteries should still be made.

This study attempted to assess reliability after fabricating pouch-type lithium-ion phosphate and applying a material for high-rate (10 C) performance based on the results of the followings in consideration of the characteristics of cathode active materials (low electrical conductivity of the lithium-ion phosphate): resistance analysis on each material when a cell is completed, change in thermal infrared radiation [9,10] and electrochemical evaluation [11–14].

Experimental

Battery manufacture and evaluation

Pouch-type $LiFePO_4$ mechanism

In $LiFePO_4$, energy is generated by the insertion-extraction reaction of Li-ion through organic electrolytes in nano-cathode active materials and natural graphite, a layered structure of negative electrode. The electromotive reaction occurs as follows in all positive and negative electrodes:

Positive reaction: $LiFePO_4 \rightarrow FePO_4 + Li^+$

Negative reaction: $FePO_4 + Li \rightarrow LiFePO_4$

Total reaction: $LiFePO_4 \leftrightarrow FePO_4 + Li^+$ (1)

During the discharge process of $LiFePO_4$, the anode active material 'Li_xC' provides electrons and lithium-ion and initiates an oxidation reaction while the cathode active material '$Li_{1-x}FePO_4$' launches a reduction reaction after getting electrons and lithium-ion. In negative electrode, consequently, lithium-ion is stored during charge process and discharged during discharge.

During a charge reaction, an electrolytic reaction occurs on the surface of negative electrode because electrolytic reduction potential is relatively higher than lithium potential. This kind of electrolytic reaction forms solid electrolyte interphase (SEI) on the electrode surface [15]. Once the SEM layer is lifted, it decreases battery performances through continuous breakage and formation.

$LiFePO_4$ cell assembly

In this study, a 1um-thick cathode LFP (Pulead, P600A) active material was used to fabricate $LiFePO_4$. As a conductive additive, super-P (Imerys) carbon black was applied. For binding, PVdF (Kureha: KF1300) was adopted. For the formation of slurries, the organic solvent 'NMP (ISP: Micropure EG)' was applied. Then, positive electrodes were fabricated through 20 μm-thick, high-purity aluminum coating. The natural graphite (POSCO, CP = 3) active material and Super P (Imerys) carbon black were mixed. After applying the CMC/SBR binder and coating the water-soluble binder-based slurries on a 10 μm-thick, high-purity (99.95%) copper-foil, anode was fabricated. The manufactured electrodes were multi-layered by stacking and folding the PE separators (W-scope: 16 μm). Then, the capacity ratio of negative to positive electrodes (N/P ratio) was set to 1.3. For the formation of 1.0 M $LiPF_6$ EC/EMC/DEC (3:5:2), an electrolyte with 2.0% electrolytic additive vinyl carbonate (VC) was injected to the battery and left at room temperature for 24 h. After that, a wetting process in which electrolytes can be wet equally in internal active materials within the electrode layer was initiated. Then, a pouch-type 20 Ah $LiFePO_4$ was fabricated.

$LiFePO_4$ cell formation and analysis of basic properties

To have a uniform and stable solid electrolyte interface (SEI) layer formed on the anode surface through 3-step formation

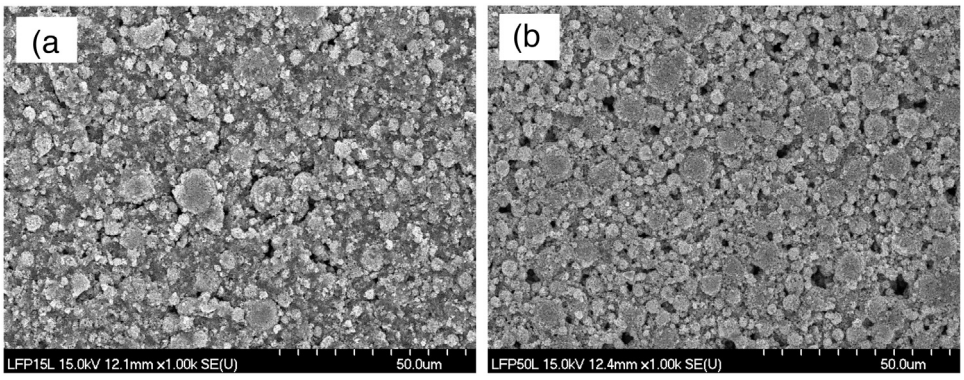

Fig. 1. SEM images by dispersion difference (a) heterogeneous, (b) homogeneous.