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Real-time monitoring of internal temperature evolution of the lithium-ion coin cell battery during the charge and discharge process

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ABSTRACT

The internal temperature is the most effective parameter to determine whether the battery is entering the danger zone. However, it is also the most difficult to be monitored in real time. This paper focuses on the real-time monitor of internal temperature evolution of the lithium-ion coin cell battery during charge and discharge. First, the experimental set-up is introduced, which consists of four parts: the embedded sensor, incubator, data transmission and collection. This shows that the internal temperatures rise rapidly at the end of the discharge process while the difference between internal temperature and surface temperature is insignificant during the 0.5 C rate charge process. With the increasing C-rate, the heat generation rate increases correspondingly. Secondly, the influence of the embedded sensor on electrochemical performance is evaluated at different C-rates. It is found that the capacity difference is about 8.28% for the 0.1 C-rate charge process between the cases with and without the embedded sensor. With the increase of the charge rate, the capacity difference becomes larger and even approached 50% under 2 C-rate. Finally, a novel thermal model is developed to determine the heat transfer parameters for the coin cell based on the monitoring data. The heat flow during 1 C and 2 C discharge tests is calculated by the thermal model and temperature curves, which has the same tendency with the experimental results using the micro-calorimeter technique.

1. Introduction

Lithium-ion batteries are widely used in portable electronics and electric vehicles such as electric vehicles (EVS), hybrid electric vehicles (HEVS), for their advantages of high energy and high power density, high voltage, enhanced lifetime and its lightweight. However, it is well known that lithium-ion batteries contain both an oxidizer (cathode) and fuel (anode as well as electrolyte) in a sealed container, which is rarely done due to the potential of the explosion. Therefore, the safety of lithium-ion batteries is a primary concern [1]. One of the most important battery safety diagnostics is the state of health (SOH), which consists of several parameters, such as voltage, current, internal battery resistance, battery temperature, ambient temperature and operation time [2]. The temperature parameter is the most crucial measure of whether the battery is in danger or not.

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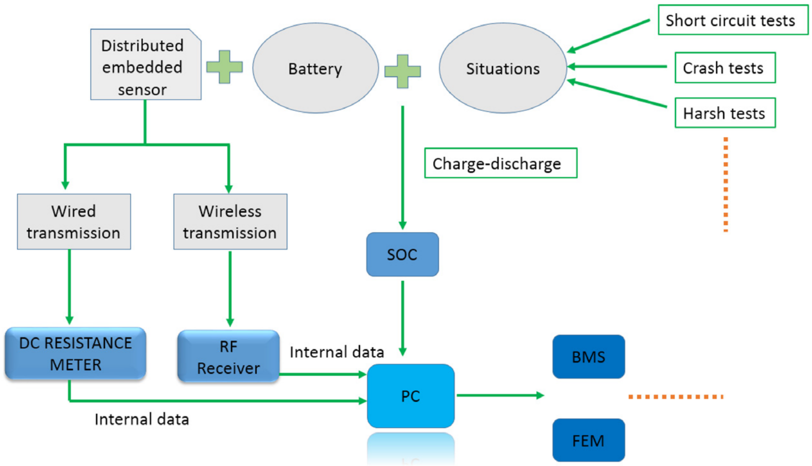

Fig. 1. General framework of the ideal internal temperature monitoring system.

When the temperature sensor begins to show a significant and rapid temperature rise, the thermal runaway is activated, causing problems such as fires, venting and electrolyte leakage.

There are many direct and indirect methods to obtain internal temperature. Most of previous researchers have focused on the monitoring of the surface temperature using thermocouples adhered to the surface of batteries [3–5]. Chacko [5] compared the surface temperature distribution of lithium-ion polymer battery in the experiment with the thermal model. The temperature of the positive terminal was higher than that of the negative terminal, due to the lower electrical conductivity of the positive electrode. Thus high temperature area appeared near the positive tab. Yang [6] monitored the real-time surface temperature of lithium battery by fiber Bragg sensors. Furthermore, some researchers proposed thermal models to establish the relation between internal temperature fields with the measured data [7–10].

It is difficult to measure the internal temperature in real time. However, it is much faster and more accurate compared with measuring the cell surface temperature. Some researchers have tried to embed the T-thermocouples in pouch cells or cylinder cells [11–13] to monitor the internal temperature in real time. Forgez [14] tested a cylindrical LiFePO4/graphite lithium-ion battery with periodic current pulses and discussed the internal and surface temperature curve of the battery under various current and ambient temperature conditions. The parameters were calculated by the simplified equivalent electric circuit method, which could be used to distinguish the internal temperature from surface temperature. Lee Chi Yuan [15–17] developed a resistance microsensor, which is small enough to be embedded into a coin cell to measure the real-time internal voltage, current and temperature simultaneously. The measurement is effective and the influence on the batteries' capacity is small. It is more suitable for engineering application in the future, however, the technology on the monitoring of the internal temperature of batteries is at early stages. Both the fundamental scientific problems and engineering applications need to be studied in depth. We summarized the requirements for the monitor of the internal temperature of batteries as follows: (1) small in size, to reduce the influence on the electrochemical performance of the battery. (2) real time, to measure the internal temperature in real time. (3) distributed, to monitor the internal temperature field; (4) wireless, to ensure the sealing and safety of the battery; (5) low cost, to be used widely.

Fig. 1 shows the desired way for real-time temperature monitoring. The small-size embedded sensors are distributed in the battery and the internal temperature data can be transmitted through the wireless or the wired way. The temperature curve reflects the heat generated and thermal transfer. The internal resistance of a battery, which tends to drift or change as the cell ages or degrades, partly accounted for the heat generation. Thus, further study on the battery management system (BMS) and finite element model (FEM) can be developed based on the monitor results. In this paper, we focused on the real-time monitoring of internal temperature in a coin cell through the wired way using the resistance temperature sensor. First, the experimental was set up; then internal temperature evolution of the lithium-ion battery during charge and discharge at various C-rate was discussed in detail. Based on the thermal model, some important thermal parameters of the battery and the heat generation rates were finally determined.

2. Experimental setup

The real-time experimental setup, as shown schematically in Fig. 2, consists of four parts: (1) the embedded sensor part. The PT1000 commercial temperature sensor is manufactured by the Germany Heraeus, 0.003851 ± 0.000004 ohm/ohm/°C. Its size is 2.3 mm $*$ 2.0 mm and the thickness is 0.9 mm. The measuring scope goes from -50 °C to 400 °C. (2) data transmission part. The sensor was placed between two isolation diaphragms in a coin cell facing the cathode electrode, as shown in Fig. 4. The copper foil connected the sensor inside the coin cell with DC RESISTANCE METER through the gap between the top and bottom cap as a wire. Moreover, the copper foil and the sensor were covered by a 50μm thick polyimide (PI) foil, which is non-conductive and does not react with the electrolyte. (3)