Int. J. Electrochem. Sci., 8 **(2013)** 4131 - 4141

International Journal of
ELECTROCHEMICAL
SCIENCE
www.electrochemsci.org

Lithium-ion Battery Module Temperature Monitoring by Using Planer Home-Made Micro Thermocouples

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Received: 26 December 2012 / *Accepted:* 4 February 2013 / *Published:* 1 March 2013

The battery management system is important to the safety of lithium-ion batteries. Safety is determined from the increase in temperature during operation. A traditional thermocouple is too large to insert in a lithium-ion battery module. Therefore, planar home-made micro thermocouples are fabricated on flexible substrates to monitor temperature in lithium-ion battery modules. Several planar home-made micro thermocouples are installed in lithium-ion battery modules to collect temperature data from the anode tab, the cathode tab and the surface of the aluminum can. These data can be used to anticipate the thermal runaway of a lithium-ion battery module and to support a battery management system.

Keywords: Planer home-made micro thermocouple, lithium-ion battery module, thermal runaway

1. INTRODUCTION

Lithium-ion batteries are widely used because they have a high specific energy, a high energy density, a long cycle lifetime, a low self-discharge rate, and a high operating voltage [1]. They can store unused solar energy, wind energy, hydroelectric energy, geothermal energy and energy from other sources. One important application of the lithium-ion battery is portable energy storage.

Portable energy storage is used in mobile phones, notebooks and electric cars. Accordingly, safety is an important issue in lithium-ion battery research. The formation of lithium dendrites and the high reactivity of metallic lithium with organic solvents can be hazardous [2]. Unwanted reactions among the battery components and the electrolyte that are activated by unforeseen local overheating or short circuits can rapidly increase the temperature of the battery and eventually trigger a fire or explosion [3]. Heat generation and thermal management are crucial the safe operation of lithium-ion cells [4]. Explosive accidents and fire-related incidents that involve Li-ion batteries are still frequently recorded; however, most incidents appear to involve overcharging or overheating [5].

In this work, planar home-made micro thermocouples are designed and fabricated on a flexible substrate. Temperature data from the anode tab, the cathode tab and the surface of an aluminum can are picked up for thermal analysis. This analysis supports a battery management system.

2. METHODOLOGY

A thermocouple consists of two conductors that are made of different materials that generate a voltage close to the point where they are in contact. When any conductor is subjected to a thermal gradient, it generates a voltage. This effect is known as the thermoelectric effect or the Seebeck effect. The generated voltage depends on the difference between the temperature of the junction and the other parts of the conductors. Any junction between dissimilar metals generates an electric potential that is a function of this temperature difference [6]. In figure1, the difference between the temperatures at point A and B is related to the electric potential difference between conductors 1 and 2 at point B.

$$\varepsilon = \oint \vec{f}_{non-static} \bullet d\vec{l} = \Delta V = S\Delta T \qquad \text{(1)}$$

where ε is the electric potential difference between conductors 1 and 2 at point B; S is the Seebeck coefficient, and ΔT is the difference between the temperatures at points A and B.

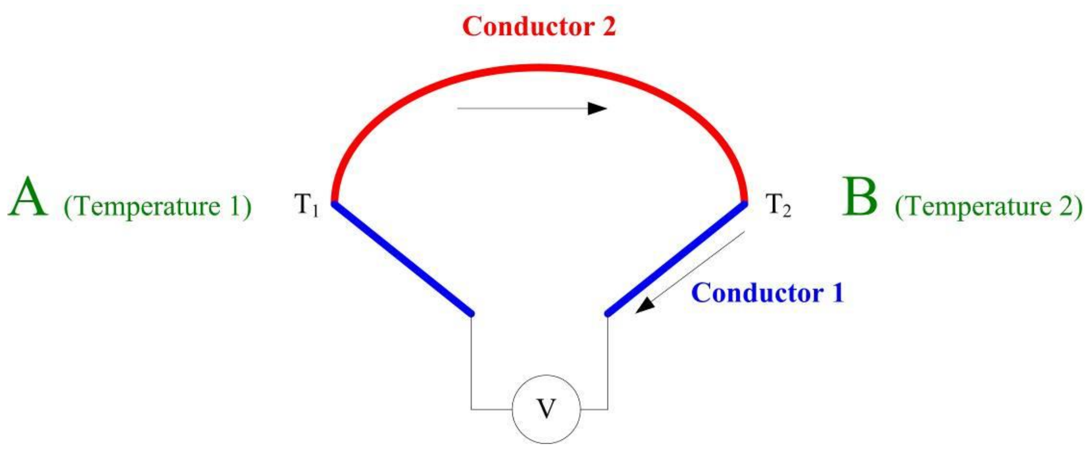

Figure 1. The schematic diagram of thermocouple.

3. DESIGN AND FABRICATION

A thermocouple is a good device for measuring temperature, but a traditional thermocouple is too large to insert in a lithium-ion battery module. In this study, copper and nickel are utilized as the two conductors in the planar home-made micro thermocouple, because of the large difference between their Seebeck coefficients and their excellent calibration curves [7, 8]. The copper-nickel thermocouple has a Seebeck coefficient of 21.3μV/K at room temperature [9]. Copper and nickel lines with a diameter of 100μm are used to fabricate the planar home-made micro thermocouple. Figure 2 presents the design of a planar home-made micro thermocouple.

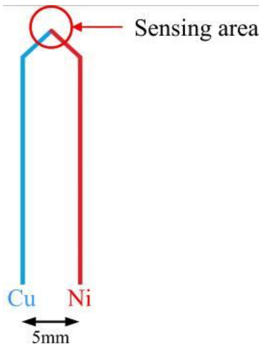

Figure 2. The design of a planar home-made micro thermocouple.

The fabrication of a planar home-made micro thermocouple is described below, and shown in figure 3. A 50μm-thick polyimide foil was used as a substrate. Polyimide foil is anti-erosive, and resists both stress corrosion and thermal corrosion [10]. It is therefore used as a protective layer and an insulating layer. The oxide on the copper line and the nickel line was removed using 10% sulfuric acid. The copper line and nickel line crossed at point A on the polyimide foil. Finally, the polyimide foil was covered with a protective layer and the fabrication of planar home-made micro thermocouple was complete.

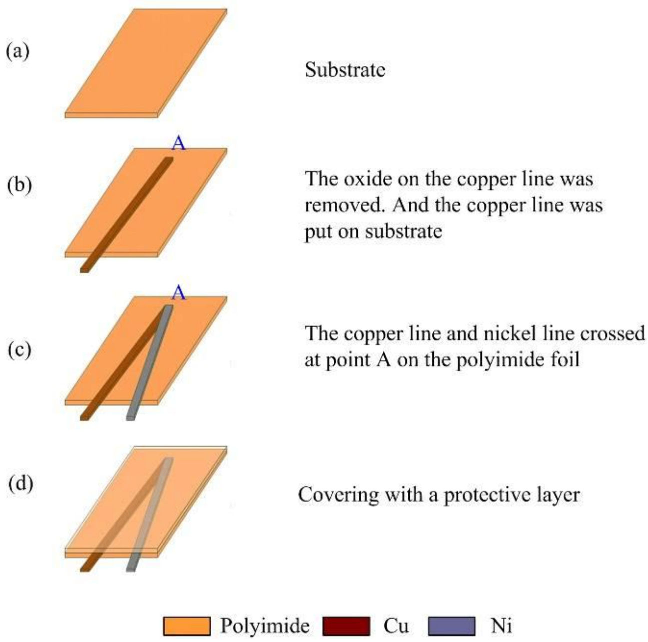

Figure 3. The fabrication of a planar home-made micro thermocouple.

4. RESULTS AND DISCUSSION

4.1. Calibration of Planar Home-made Micro Thermocouples

The sensing area of the planar home-made micro thermocouple was immersed put in water. The temperature of the water was controlled from 20°C to 100°C using a programmable hot plate. The voltage signal was picked up using a Data Acquisition System, as displayed in figure 4. Figure 5 plots the calibration curves of planar home-made micro thermocouples. The calibration curves were highly repeatable and revealed a linear relationship between temperature difference and voltage.

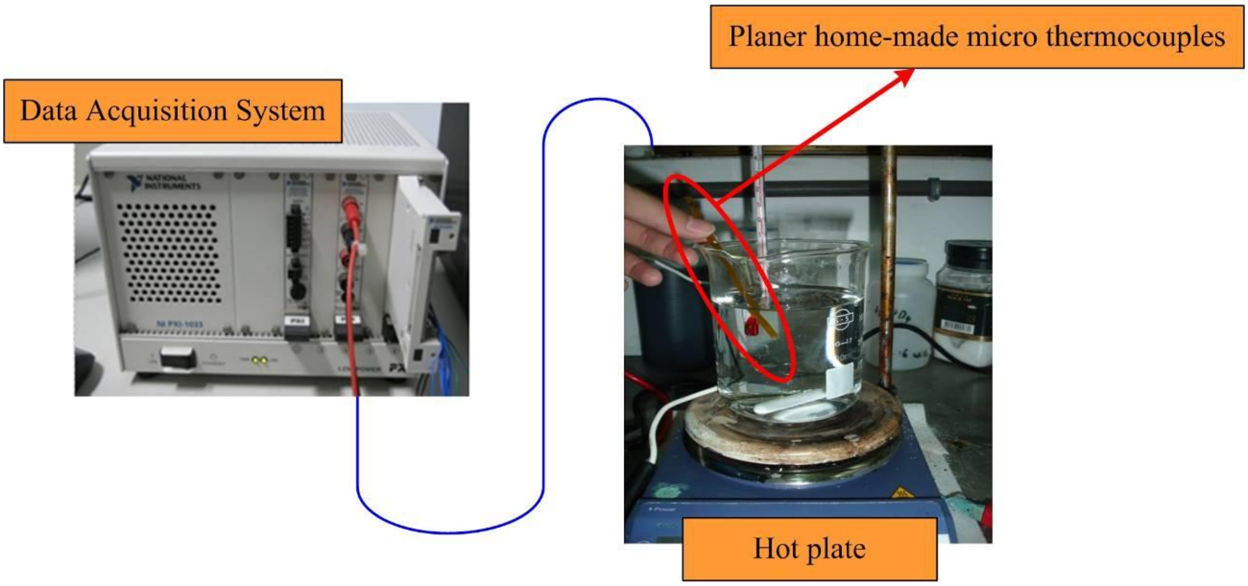

Figure 4. The voltage signal is picked up by Data Acquisition System.

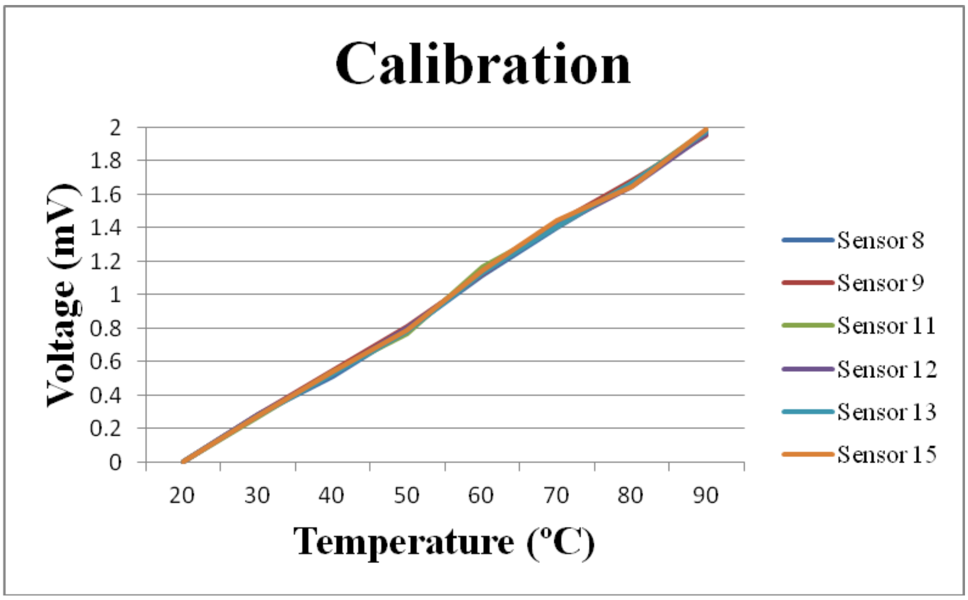

Figure 5. The calibration curves of planar home-made micro thermocouples.

4.2. Charge and Discharge Test

A Lithium Iron Phosphorous Oxide battery (LFPO) is used in this investigation. Its dimensions are 32mm (H) x 155mm (L) x 125mm (W). Its capacity is 50Ah. Its nominal voltage is 3.2V and energy density is 265Wh/L. Six planar home-made micro thermocouples are placed in different positions a lithium-ion battery module, as shown in figure 6. The planer home-made micro thermocouples' serial number is no.8, no.9, no.11, no.12, no.13, and no.15.

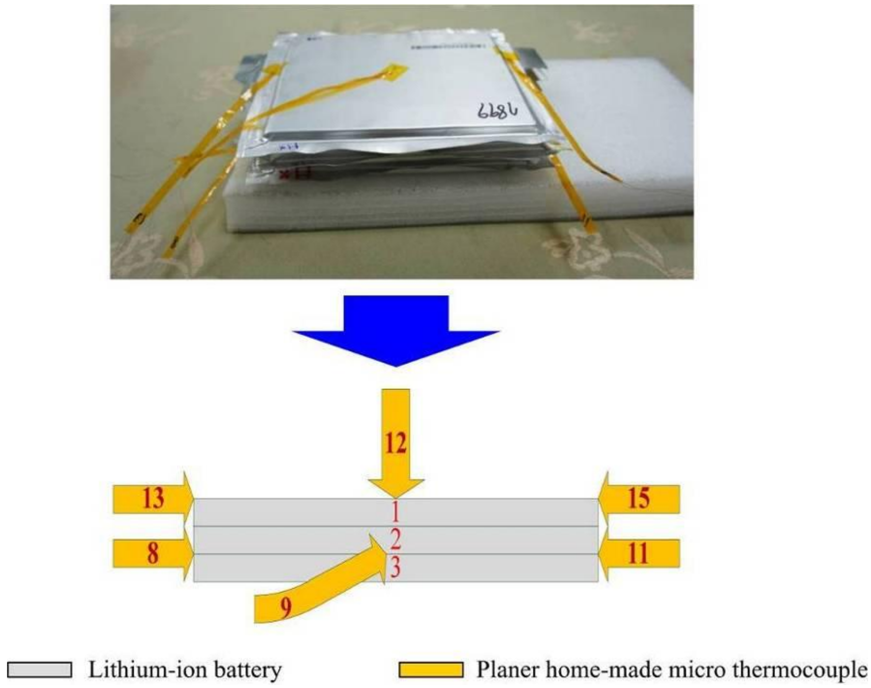

Figure 6. Six planar home-made micro thermocouples are placed in different positions a lithium-ion battery module.

Figure 7 depicts the battery tester that was used to charge and discharge the lithium-ion battery module. The ambient temperature was 23°C. Table 1 presents the process of the battery test.

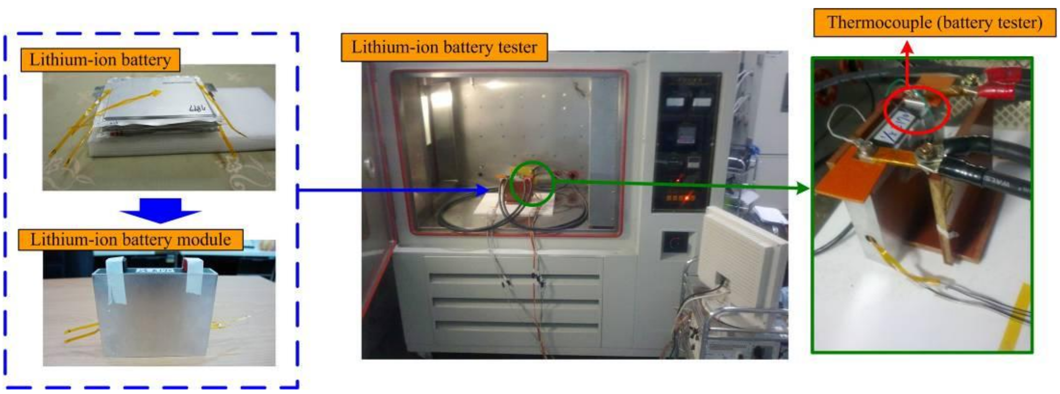

Figure 7. The battery tester that was used to charge and discharge the lithium-ion battery module.

Table 1. The process of the battery test.

Step	Action	Test C-rate	Setting time
1	Charge	0.5C	CC-CV (3.65V to 0.05C)
2	Rest	-	30min
3	Discharge	0.5C	CC to 2V
4	Rest	-	30min
5	Charge	1C	CC-CV (3.65V to 0.05C)
6	Rest	-	30min
7	Discharge	1C	CC to 2V
8	Rest	-	30min
9	Charge	3C	CC-CV (3.65V to 0.05C)
10	Rest	-	30min
11	Discharge	3C	CC to 2V
12	Rest	-	30min

Figure 8 displays the temperature changes of anode tab, cathode tab and the surface of the aluminum can, and electrical potential difference between anode tab and cathode tab. Figure 9 plots seven temperature signals from six planar home-made micro thermocouples and the thermocouple in a lithium-ion battery tester. The seven temperature signals are almost the same during battery charge and discharge. The interior temperature of the battery module exceeds exterior temperature.

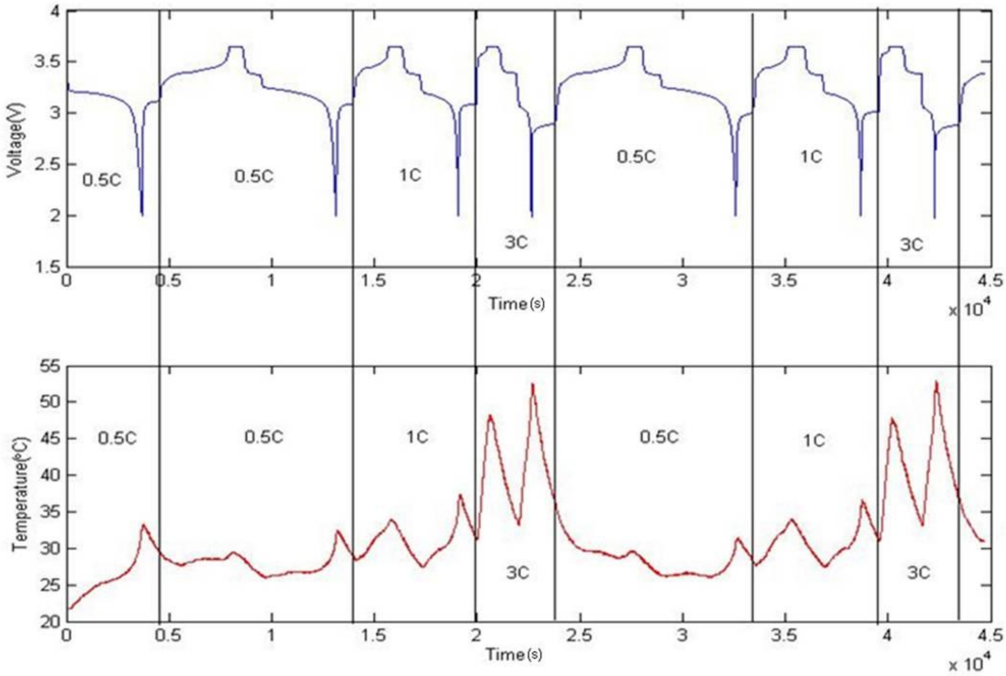

Figure 8. The temperature changes of anode tab, cathode tab and the surface of the aluminum can, and electrical potential difference between anode tab and cathode tab.

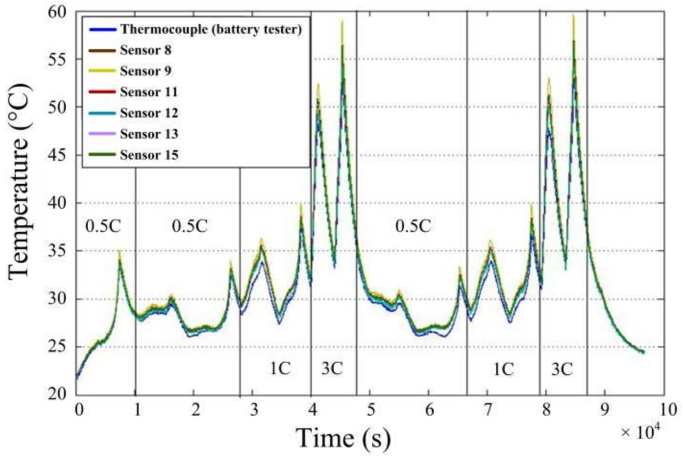

Figure 9. The seven temperature signals from six planar home-made micro thermocouples and the thermocouple in a lithium-ion battery tester.

4.3. Comparison of Temperatures of Anode Tab and Cathode Tab

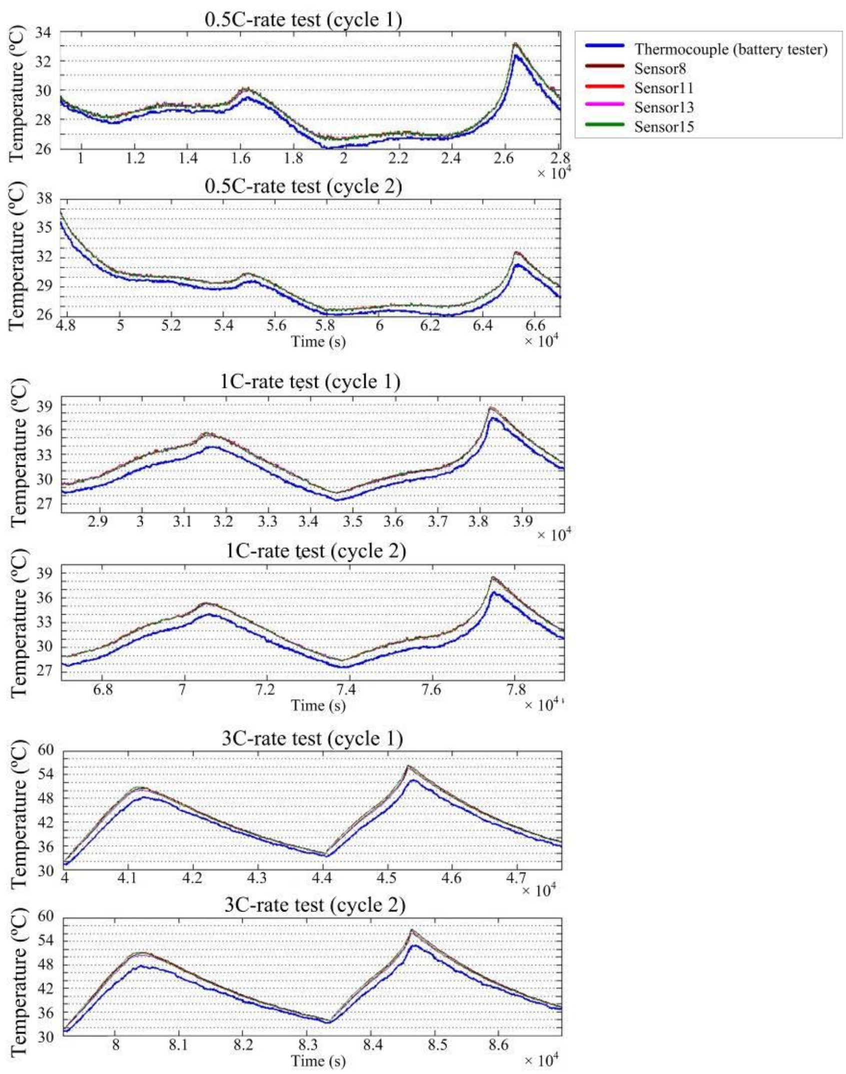

Figure 10. The temperature curves in 0.5C-rate, 1C-rate, 3C-rate battery tests.

The electrode tab is important to the flow of electric current. If the contact area of the electrode tab is too small, then the density of the electric current through it will be excessive. The temperature of the electrode tab will therefore rise. Accordingly, the size of the electrode tab is important to ensure the safety of the battery. Number 8, 11, 13 and 15 planar home-made micro thermocouples are set on the electrode tab of a lithium-ion battery module. Figure 10 plots the temperature curves in 0.5C-rate, 1C-rate, 3C-rate battery tests.

The temperature difference between the electrode tab and the aluminum can is 0.5°C in 0.5C-rate, 1°C in 1C-rate test and 4°C in 3C-rate test. The electric current density rises at the electrode tab, increasing the difference between the temperature of that tab and the aluminum can.

4.4. Comparison of Temperatures in Different Positions of Lithium-ion Battery Module

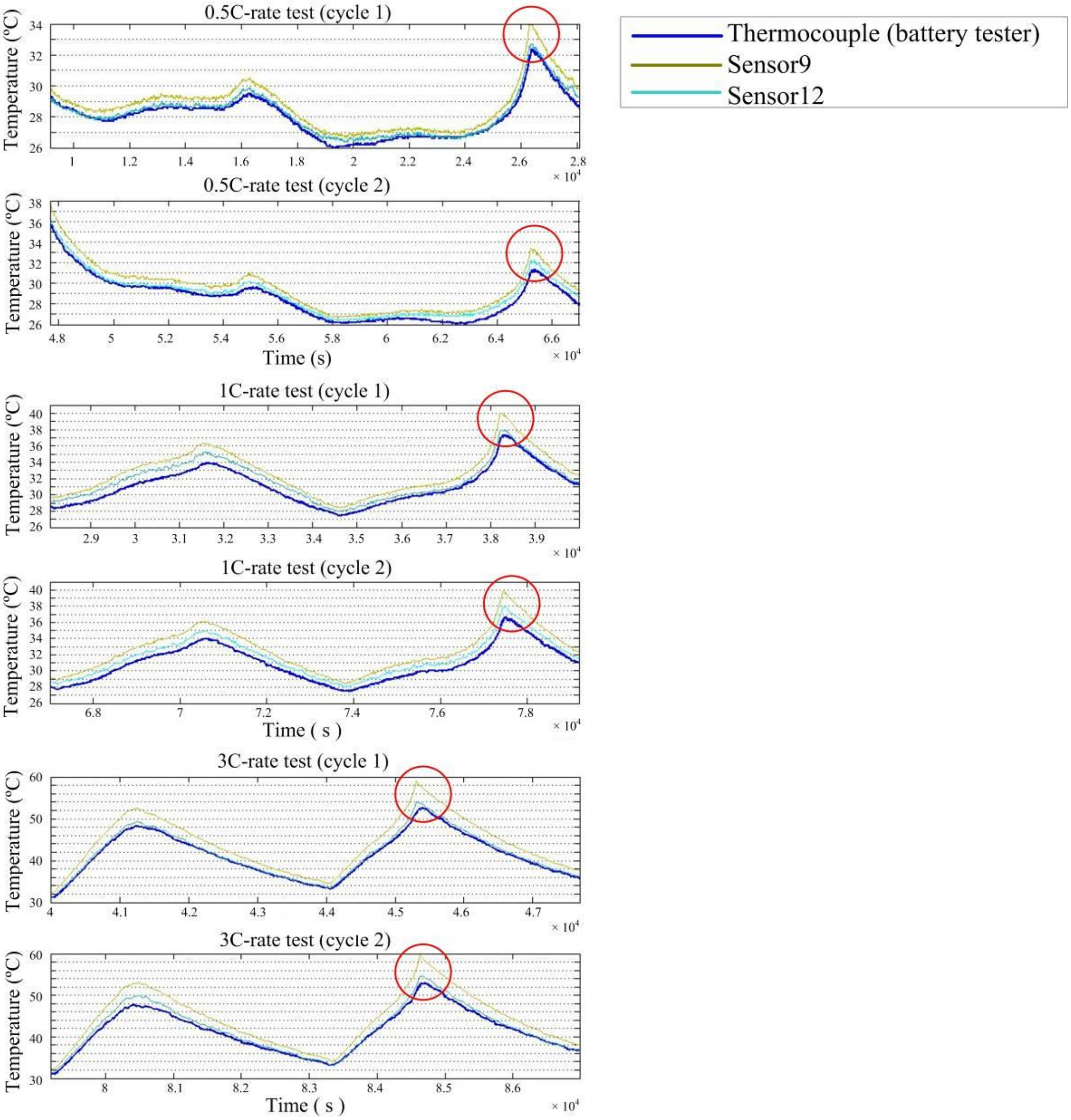

Figure 11. The differences between the temperatures of the aluminum can at sensor 9 and sensor 12 in 0.5C-rate, 1C-rate, 3C-rate battery tests.

The temperatures vary among different positions in the lithium-ion secondary battery. The inner temperature changes more rapidly than the outer temperature [11]. A lithium-ion battery is packed in an aluminum pouch. The aluminum pouch is coated with a layer of a polymer material to reduce the dissipation of heat. Figure 11 plots the differences between the temperatures of the aluminum can at sensor 9 and sensor 12 in different C-rate tests. The temperature of sensor 9 is 2°C higher than that of sensor 12 in a 0.5C-rate test. The temperature of sensor 9 is 4°C higher than that of sensor 12 in a 1C-rate test, and 8°C higher in a 3C-rate test. These data demonstrate heat dissipation, which always indicates the non-ideality of the device.

4.5. Monitoring Inner Temperature of Lithium-ion Battery Module Yields Information on Thermal Conditions of Battery Faster than Monitoring Outer Temperature

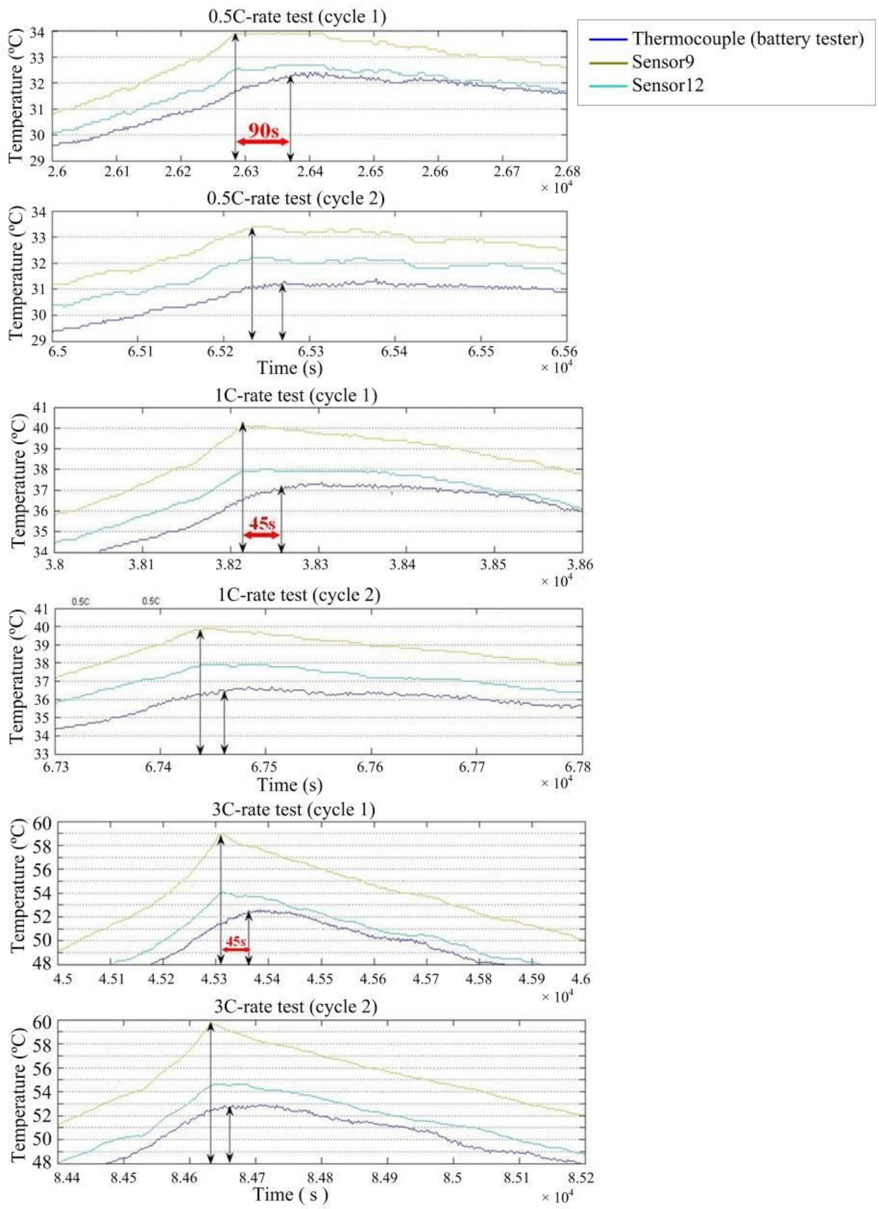

Figure 12. The planar home-made micro thermocouples could pick up signal faster than thermocouple battery tester.

Planer home-made micro thermocouples that are inserted in a lithium-ion battery module can pick up accurate data. It provides the important advantage that monitoring the inner temperature yields information on thermal changes 45~90 seconds before monitoring the outer temperature, as displayed in figure 12. The battery management system can therefore receive useful temperature data early. It is therefore useful in researching the safety of lithium-ion battery modules.

5. CONCLUSION

The temperature of the electrode tab was 0.5ºC higher than that of the aluminum can in a 0.5C-rate test. It was 1ºC higher in a 1C-rate test and 4ºC higher in a 3C-rate test. Figure 10 indicates that the temperature difference between the electrode tab and the aluminum can is lower in a higher C-rate test, because the electric current is larger.

The internal temperature was a maximum of 1.5ºC greater than the external temperature at its peak in the 0.5C-rate charge test, as shown in figure 11. It was a maximum of 2ºC higher at its peak in the 1C-rate charge test and a maximum of 6ºC higher at its peak in the 3C-rate charge test.

The internal temperature was a maximum of 2ºC higher than the external one at its peak in 0.5 C-rate discharge test, as plotted in figure 11, a maximum of 4ºC higher in the 1C-rate discharge test, and a maximum of 8ºC higher in the 3 C-rate discharge test. These results in figure 11 reveal that the difference between the internal and external temperatures is lower in a higher C-rate test, because the electrochemical reaction is more vigorous.

The electrochemical discharge reaction is more vigorous than the charge reaction, so the maximum temperature is higher in discharge than charge.

Monitoring inner temperature is 45~90 seconds faster than monitoring outer temperature, as displayed in figure 12, in providing useful information about the thermal conditions of a lithium-ion battery module, which can be provided to a battery management system. The monitoring of interior temperature is therefore useful for research into the safety of lithium-ion battery modules.

ACKNOWLEDGEMENTS
This work was accomplished with much needed support and the authors would like to thank the National Science Council of R.O.C. through the grant NSC 99-2632-E-155-001-MY3. In addition, we would like to thank the YZU NENS Common Lab, Chang Hong Energy Technology Co., Ltd for providing access to their research facilities.

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