In Situ Monitoring of Temperature and Voltage in Lithium-ion Rechargeable Batteries using Flexible Micro Two-in-one Sensors

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ABSTRACT

Under overcharge conditions, the interior temperature of polymer lithium-ion rechargeable batteries will rapidly increase. Such batteries are adopted in electric vehicles that require rapid charging and discharging, and this process causes rapid heating, raising safety issues, including thermal runaway and even potential explosion. Hence, flexible micro two-in-one sensors for the in-situ monitoring of temperature and voltage in polymer lithium-ion rechargeable batteries must be developed. Traditional instruments are too large to be used to measure temperature and voltage inside polymer lithium-ion rechargeable batteries. In this work, the micro-electro-mechanical systems (MEMS) is utilized to develop flexible micro two-in-one sensors for the in-situ monitoring of temperature and voltage within a lithium-ion rechargeable battery.

Keywords: micro-electro-mechanical systems, flexible micro two-in-one sensors, polymer lithium-ion rechargeable battery, in- situ monitoring

1 INTRODUCTION

In recent years, lithium-ion rechargeable batteries have been widely utilized in commercial products, including mobile phones, notebooks, communication and consumer electronic (3C) products and electric vehicles. The safety and efficiency of lithium-ion rechargeable batteries are extremely important. The safety of a polymer lithium-ion rechargeable battery depends on the electrolyte, separator, anode and cathode [1,2]. During rapid charging and discharging, metallic lithium can separate out as dendrites and acicular crystals [3], reducing the efficiency of the battery and raising a safety issue [4,5]. Traditional thermocouples are too large to measure the internal temperature in polymer lithium-ion rechargeable batteries causing damage [6]. The authors already have experience of developing flexible micro temperature sensors for monitoring temperature within such a battery [7]. However, the thinness of micro sensors makes placing them into a lithium-ion rechargeable battery very difficult.

2 METHODOLOGY

2.1 Theory of Temperature Sensor

In this investigation, a gold thermally sensitive resistor (RTD), whose resistance varies with temperature, is employed to measure temperature. Thin-film gold-RTD sensors have numerous favorable characteristics. They are small and highly accurate; their response time is short; arrays of them can be mass-produced and placed anywhere in lithium-ion rechargeable batteries. In this work, a gold thermally sensitive resistor with a serpentine structure is designed and constructed.

The resistance of a general metal is given by

$$R = \rho L / A \tag{1}$$

where R represents resistance (Ω); ρ is resistivity (Ω m); L is length of the wire (m), and A is cross-sectional area (m^2). In range of temperatures over which the resistance of the RTD varies linearly, the relationship between measured resistance and temperature change satisfies

$$R_t = R_r(1 + \alpha_T \Delta T) \tag{2}$$

where R_t is resistance at t°C; R_r is resistance at r°C, and α_T is the sensitivity (1/°C) of the temperature sensor.

Eq. (2) can be rearranged to

$$\alpha_T = \frac{R_t - R_r}{R_r(\Delta T)} \tag{3}$$

2.2 Theory of Voltage Sensor

In this investigation, a film-type probe is embedded in a lithium-ion rechargeable battery to measure the voltage at particular locations. The sensing area of the micro voltage sensor was 600μm × 600μm. The rest of the conducting wire was insulated.

3 FABRICATION OF FLEXIBLE MICRO TWO-IN-ONE SENSORS

The thin film of parylene resists corrosion by both high temperature and stress. In this investigation, parylene thin film is used as a protective layer and a flexible substrat. Figure 1 presents the fabrication of the flexible micro two-in-one sensor. Procedure for fabricating flexible micro two-in-one sensor is fabricated as follows.

Silicon wafers with a diameter of 4 inches (Fig. 1-a) were cleaned as the substrates of the micro two-in-one sensors. A 300Å-thick copper sacrificial layer (Fig. 1-b) was deposited on the wafer by electron beam evaporation. A 5μm-thick parylene thin film (Fig. 1-c) was then deposited by physical vapor deposition (PVD) as a flexible protective layer. AZ 4620 photoresist (PR) was spin-coated onto the wafer, which was then baked for 5 mins at 90°C. Figure 1-d displays the pattern defined on the micro two-in-one sensors by exposure to UV and the use of an MP2500 developer. A 250Å-thick chromium adhesion layer and a 2000Å-thick conduction layer were deposited in that order on the wafer via electron beam evaporation, and the photoresist was removed using the lift-off process that is shown in Fig. 1-e. Another parylene layer was deposited to protect the structure, as presented in Fig. 1-f. Reactive ion etching (RIE) was carried out with a mask to define the patterns on the contact pads and the sensing region that are displayed in Figs. 1-g and h. Figure 2 shows an optical microscopic photograph of the flexible micro two-in-one sensor.

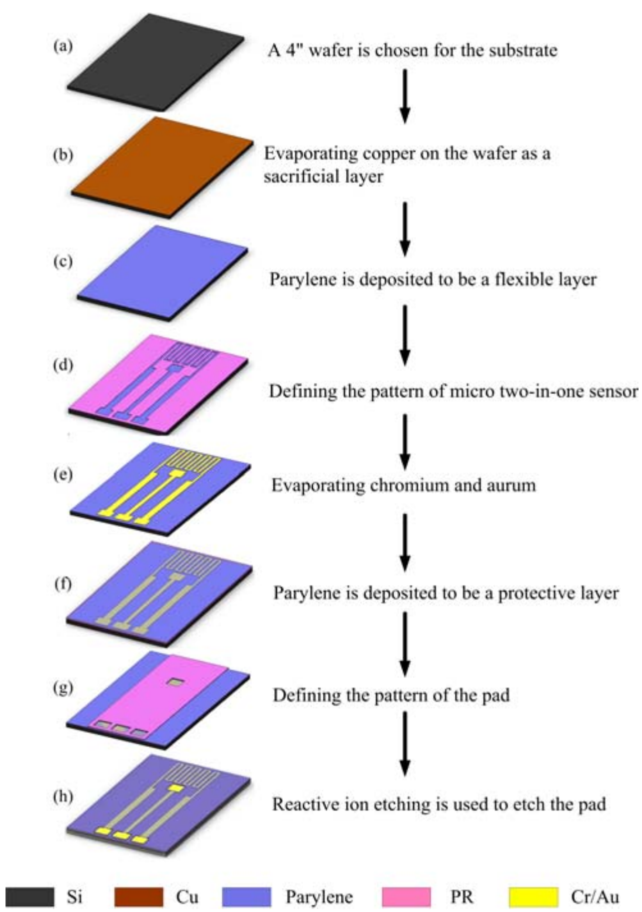

Figure 1: Procedure for fabricating flexible micro two-in-one sensor.

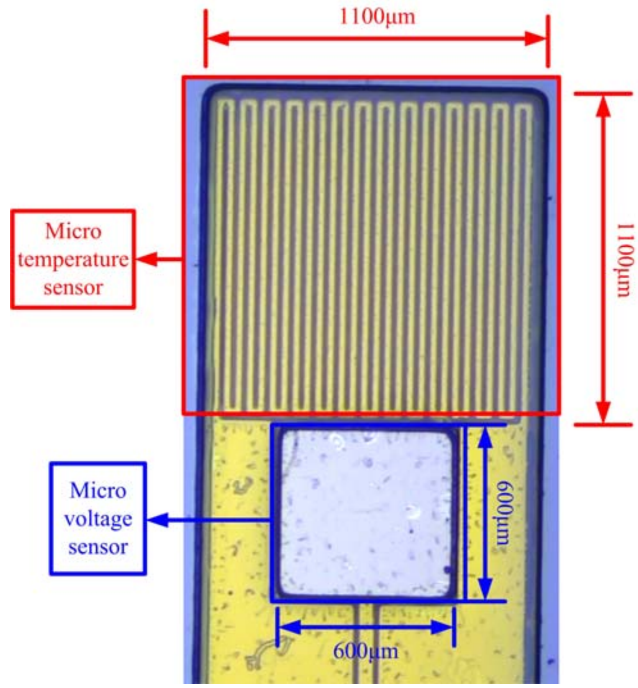

Figure 2: Optical microscopic photograph of flexible micro two-in-one sensor.

4 RESULTS AND DISCUSSION

4.1 The Calibration of Micro Two-in-one Sensors

The flexible micro two-in-one sensors were initially placed in a programmable temperature and humidity chamber and connected to a data acquisition system for calibration. The calibration curve in Fig. 3 reveals the high repeatability and linearity of the relationship between temperature and resistance.

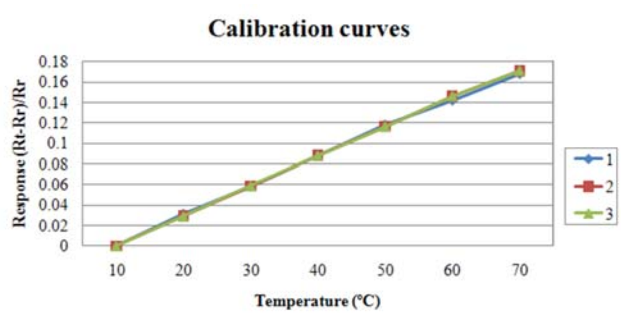

Figure 3: Calibration curve of micro temperature sensor.

The flexible micro two-in-one sensors were inserted into a polymer lithium-ion rechargeable battery, as displayed in Fig. 4.

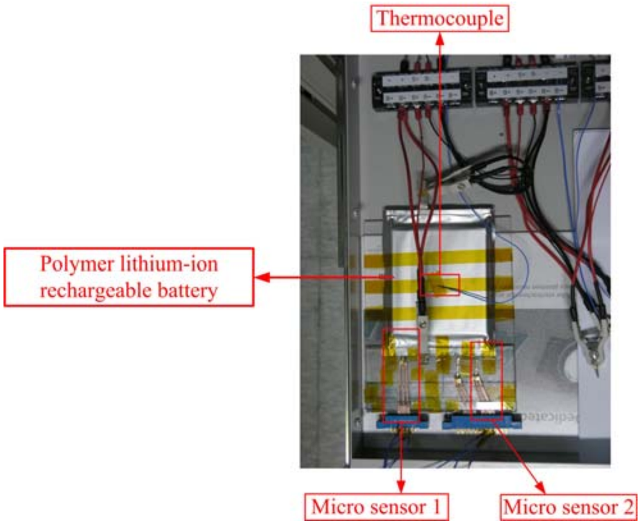

Figure 4: Flexible micro two-in-one sensors were inserted into a polymer lithium-ion rechargeable battery.

NI PXI 1033 was utilized to pick up the signal from the flexible micro two-in-one sensors, and the polymer lithium-ion rechargeable battery was charged and discharged using GBT 2211, as shown in Fig. 5.

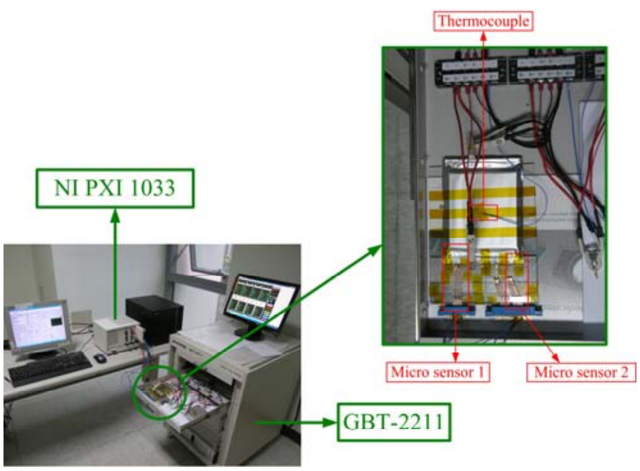

Figure 5: Testing system that consists of flexible micro two-in-one sensors in a polymer lithium-ion rechargeable battery.

The results demonstrate that when charging and discharging reactions proceeded in the polymer lithium-ion rechargeable battery, the internal temperature was 3°C higher than the external temperature, as presented in Fig. 6.

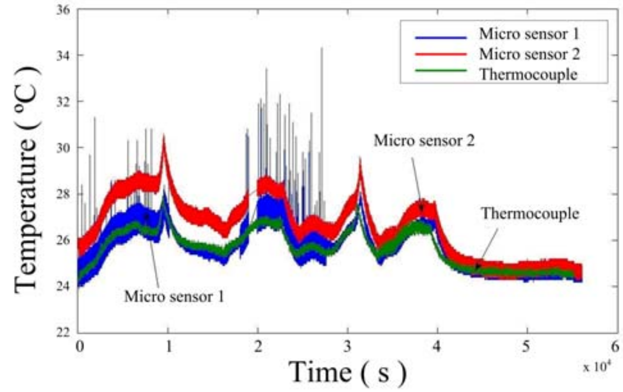

Figure 6: Temperature curve during C/2 charging and discharging.

5 CONCLUSIONS

In this work, a flexible micro two-in-one sensor that was fabricated using MEMS. The single sensor integrated temperature and voltage functions. It was newly applied to utilized *in situ* monitoring in a functioning polymer lithium-ion rechargeable battery.

The *in situ* measurements of temperature were made successfully. The results thus obtained demonstrate that charging and discharging reactions occurred in the lithium-ion rechargeable battery, the interior temperature was 3°C higher than the external temperature.

In the future, this *in situ* monitoring system will used to locate defects in a lithium-ion rechargeable battery warn of problems before they occur.

6 ACKNOWLEDGEMENTS

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