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Short Communication

In-situ Monitoring of Temperature and Voltage in Lithium-Ion Battery by Embedded Flexible Micro Temperature and Voltage Sensor

Chi-Yuan Lee[*], *Shuo-Jen Lee, Yi-Ho Chen, Ming-Yu Chung, Kuo-Chang Han,*
Yu-Ming Chang and Ming-Shao Tang

Department of Mechanical Engineering, Yuan Ze Fuel Cell Center, Yuan Ze University, Taoyuan, Taiwan
[*]E-mail: cylee@saturn.yzu.edu.tw

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Lithium-ion batteries are utilized in mobile phones, personal digital assistants (PDA), 3C products and electric vehicles. Batteries must be rapidly chargeable. They discharge in devices. In both processes, the temperature in the battery increases rapidly. Safety is very important in the operation of lithium-ion batteries. In this work, a flexible micro temperature and voltage sensor is fabricated by the micro-electro-mechanical systems (MEMS) process for integration on flexible film substrates. The electrolyte and heat inside the lithium batteries can influence the accuracy of measurements made by, and the lifetimes of, flexible micro temperature sensors. In this work, flexible micro temperature and voltage sensor is embedded into lithium-ion battery to acquire in situ temperature and voltage data. These data are useful for improving the safety of lithium-ion batteries.

Keywords: Flexible micro temperature and voltage sensors, micro-electro-mechanical systems, lithium-ion battery, in-situ monitoring

1. INTRODUCTION

The development of new technology for generating electricity has become an important issue in recent years. Solar energy, wind power, hydropower, geothermal energy and other energy sources have become particularly important. Power storage technology is also important for storing generated electrical energy that is not yet required. Lithium-ion batteries are particularly useful for portable devices including mobile phones, notebooks and vehicles. The safety and efficiency of lithium-ion batteries must be examined.

The electrolyte, separator, anode and cathode in a lithium battery influence its safety [1]. During rapid charging and discharging, chemical and electrochemical reactions proceed in the lithium ion cells and the lithium separates out on the electrodes in the battery. Overcharging lithium-ion cells can cause thermal runaway and possibly an explosion [2-4]. A three-dimensional transient electro-thermal model that is based on a finite volume method has been used to model the thermal behavior of lithium-ion (Li-ion) polymer cells [5]. Overcharging lithium-ion batteries can generate and unsafe voltage [6]. Traditionally, a drill is utilized to put a thermocouple in the center of the positive electrode side of such a battery to measure its interior temperature [7].

Flexible micro temperature sensors have been fabricated on parylene substrates for measuring the internal temperatures of spiral-wound lithium-ion batteries [8]. In this work, a micro temperature and voltage sensor is fabricated on a flexible substrate using micro-electro-mechanical systems (MEMS) technology and it is embedded in a laminated lithium-ion battery for measuring in situ temperature and voltage. These data are useful for the improving safety of, and supporting the development of, lithium-ion batteries.

2. METHODOLOGY

2.1. Design of a Micro Temperature Sensor

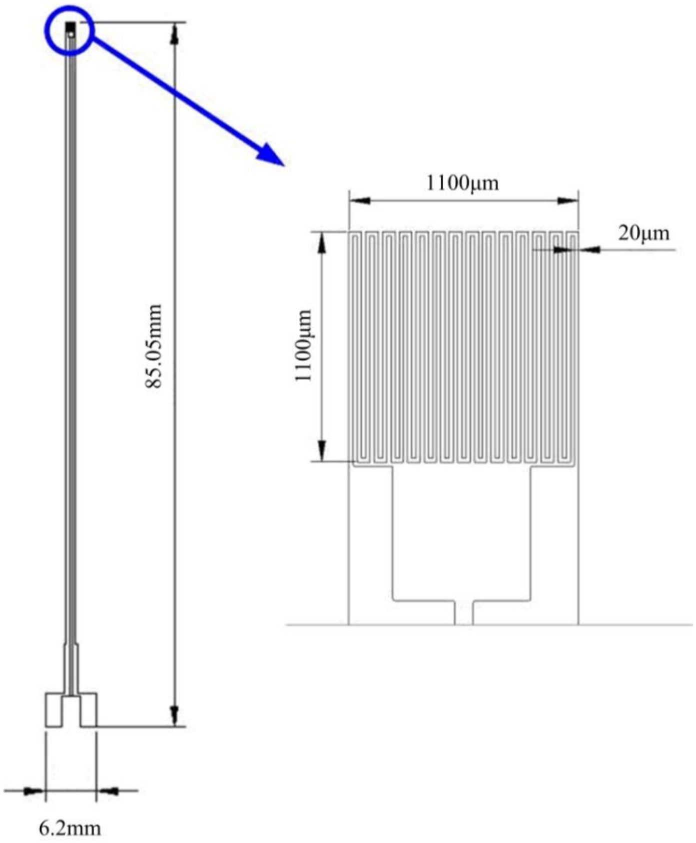

Figure 1. The design of micro gold resistance temperature detector.

Resistance temperature detectors (RTDs) exploit the variation in electrical resistance of conductors with temperature. An RTD is made from a pure material whose resistance at various temperatures is known. In this research, Au is used as the sensing material in a micro gold resistance temperature detector. The relationship between the electrical resistance of a conductor and its temperature is expressed as

$$R_t = R_r(1+\alpha\Delta T) \qquad (1)$$

$$\Delta T = t - t_r \qquad (2)$$

where R_t and R_r denote the resistance of an RTD at t °C and r °C, and α is the positive temperature coefficient thereof. ΔT is the variation in temperature from t and t_r.

The micro gold resistance temperature detector is designed with a serpentine electrode, which is shown in figure 1. The sensing area is 1100μm×1100μm, and the line width is 20μm.

2.2. Design of a Micro Voltage Sensor

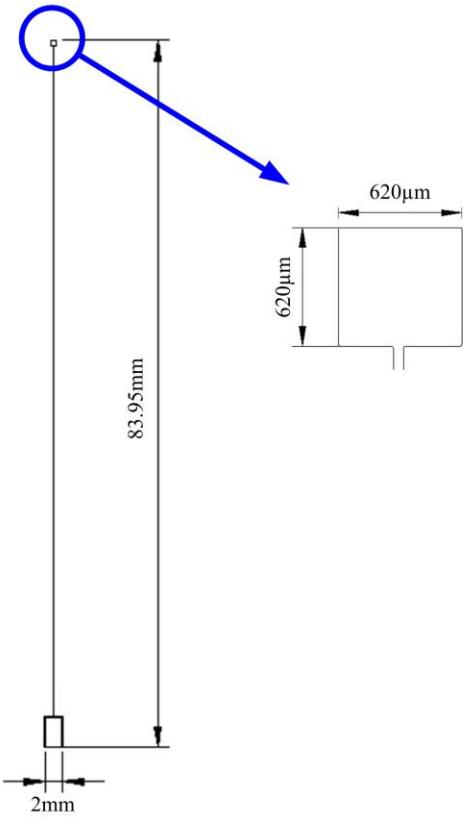

Figure 2. The design of micro voltage sensor.

The micro voltage sensor is based on Ohm's law, which specifies the relationship between two points in a conductor. Usually, it is expressed mathematically as

$$V=I\times R \qquad (3)$$

where V is the potential difference across the resistance (Volts); I is the current through the resistance (Amperes), and R is resistance of the conductor (Ω). In this work, a micro voltage probe is embedded in the anode in a lithium-ion battery, and pad is linked to cathode outer lithium-ion battery, as schematically displayed in figure 2.

3. FABRICATION

The fabrication of a micro gold resistance temperature detector and micro voltage sensor is described below, and presented in figure 3.

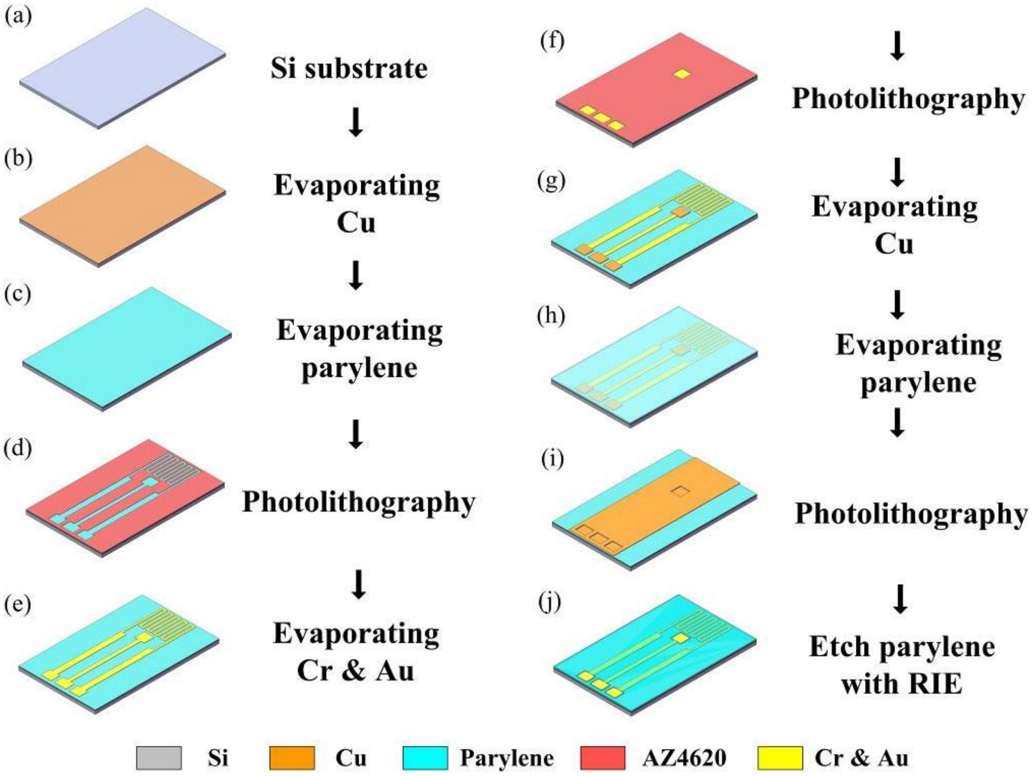

Figure 3. The fabrication of flexible micro temperature and voltage sensors.

First, a silicon wafer was used as the substrate of the micro sensors, and a 1500Å-thick layer of copper was deposited as a sacrificial layer using an e-beam evaporator. A 12μm-thick parylene thin film was deposited onto the copper layer by using physical vapor deposition (PVD), as shown in figures 3(a) ~ (c). Parylene thin film is anti-erosive, and resists both stress corrosion and high temperature. It is therefore utilized as a protective layer and an insulation layer.

Then, the lithographic process was utilized to define a pattern in the micro gold resistance temperature detector and micro voltage sensor. Both a 250Å-thick chromium layer and a 2000Å-thick gold layer were deposited as an adhesion layer and a conducting layer, respectively, by using e-beam evaporator. The microstructure of the micro gold resistance temperature detector and micro voltage sensor was patterned as presented in figures 3(d) ~ (e).

A second lithographic process was conducted to define an etching mask. The copper layer was subsequently deposited over the whole area of the wafer. The copper was etched by a lift-off process to form a stopping layer, as displayed in figures 3(f) ~ (g).

Finally, a 3μm-thick parylene thin film was deposited onto the substrate and a second etching mask is created. Reactive ion etching (RIE) was utilized to remove parylene, as shown in figures 3(h) ~ (j). Figure 4 displays an optical micrograph of the flexible micro temperature and voltage sensor.

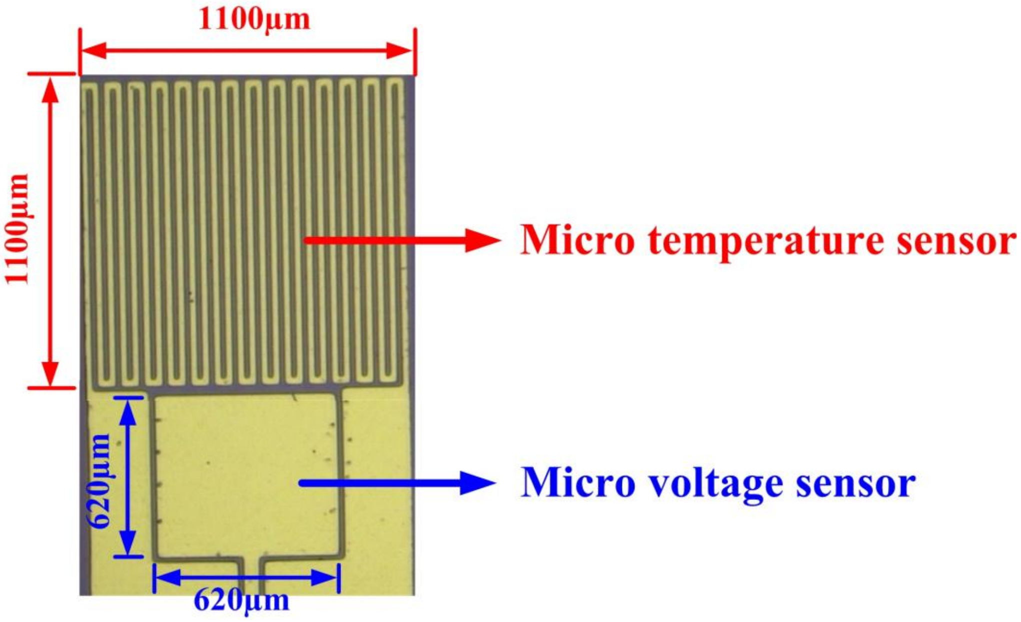

Figure 4. Optical microscopic photograph of a flexible micro temperature and voltage sensor.

4. RESULTS AND DISCUSSION

4.1. Calibration of Micro Temperature Sensors

The flexible micro temperature and voltage sensor was placed in a tester at constant temperature and humidity. The resistance signal was picked up by a Data Acquisition system, as presented in figure 5. The temperature of the constant temperature and humidity tester was increased from -20ºC to 60ºC for three times.

Figure 6 plots the calibration curves of the flexible micro temperature sensor. The calibration curve was high repeatable and revealed a linear relationship between temperature and resistance.

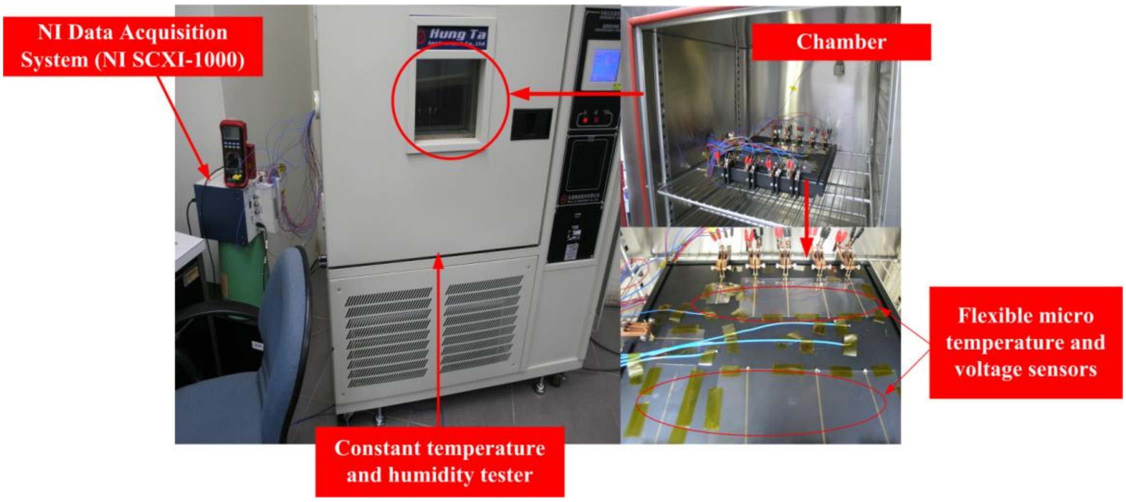

Figure 5. Thermal chamber of a flexible micro temperature sensor calibration.

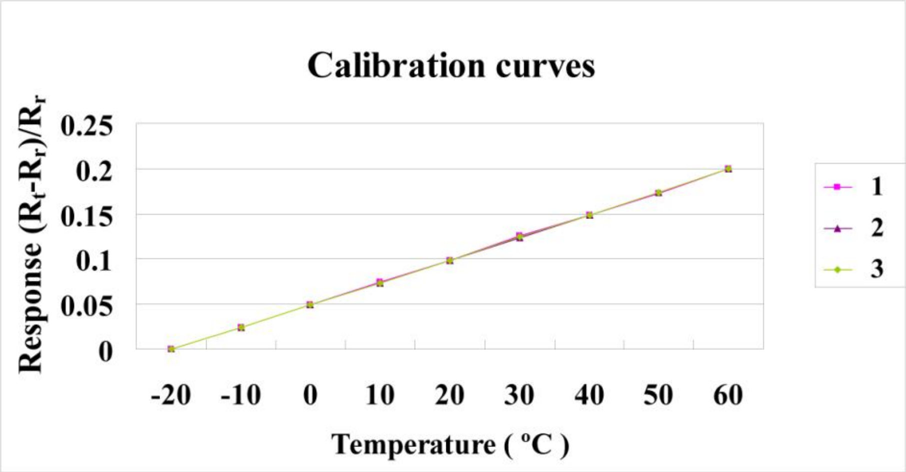

Figure 6. Calibration curves of a flexible micro temperature sensor.

4.2. Temperature Measurement in 1/2C Charging and Discharging

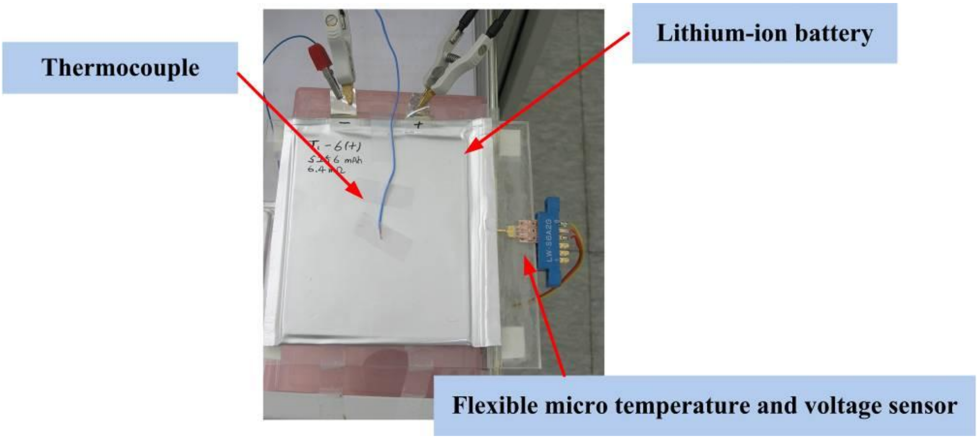

Figure 7. Flexible micro temperature and voltage sensor was inserted into lithium-ion battery.

The flexible micro temperature and voltage sensor was inserted into a lithium-ion battery, as shown in figures 7 and 8. A thermocouple was attached to the external surface of the battery to measure the surface temperature. The signals from the micro sensors and the thermocouple were acquired by the Data Acquisition system GBT-2211.

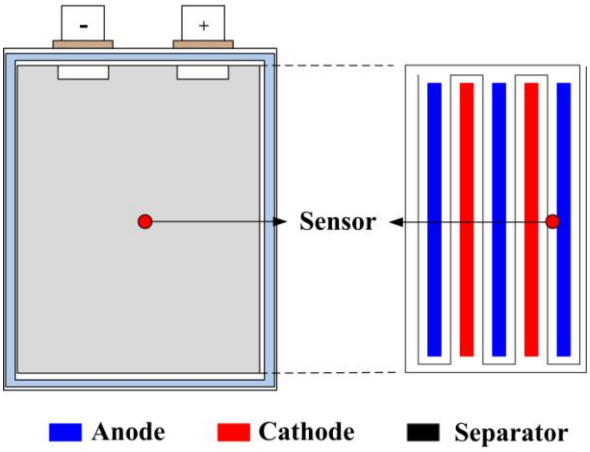

Figure 8. Position of micro temperature and voltage sensor in lithium-ion battery.

Figure 9 presents the battery tester that was used to charge and discharge the lithium-ion battery. Figure 10 plots the temperature curves of the thermocouple and the micro temperature sensor. The two curves were all mutually consistent. The temperatures varied with the position of inside and outside lithium-ion battery. The internal temperature changed more rapidly than the external temperature. At its peak, the internal temperature was a maximum of 0.86ºC higher than the external one. Figure 11 plots the voltage curve of the micro voltage sensor. The external voltage was a maximum of 0.525V higher than internal one in charge process. In discharge process, the internal voltage was a maximum of 0.483V higher than external one.

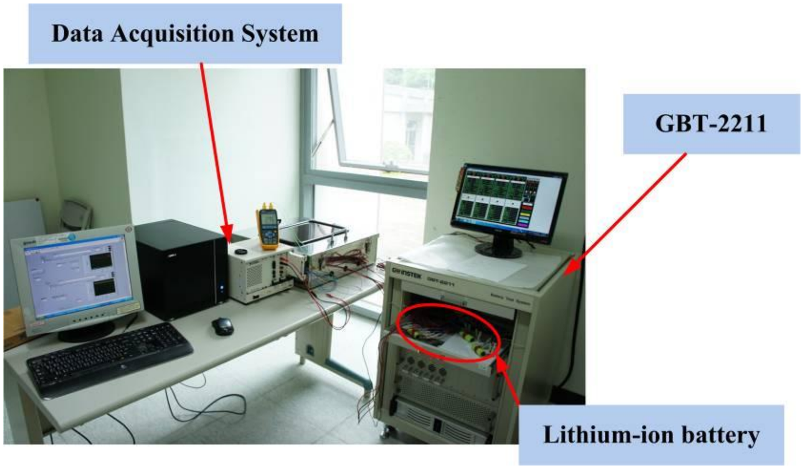

Figure 9. GBT-2211 is used to charge and discharge the lithium-ion battery.

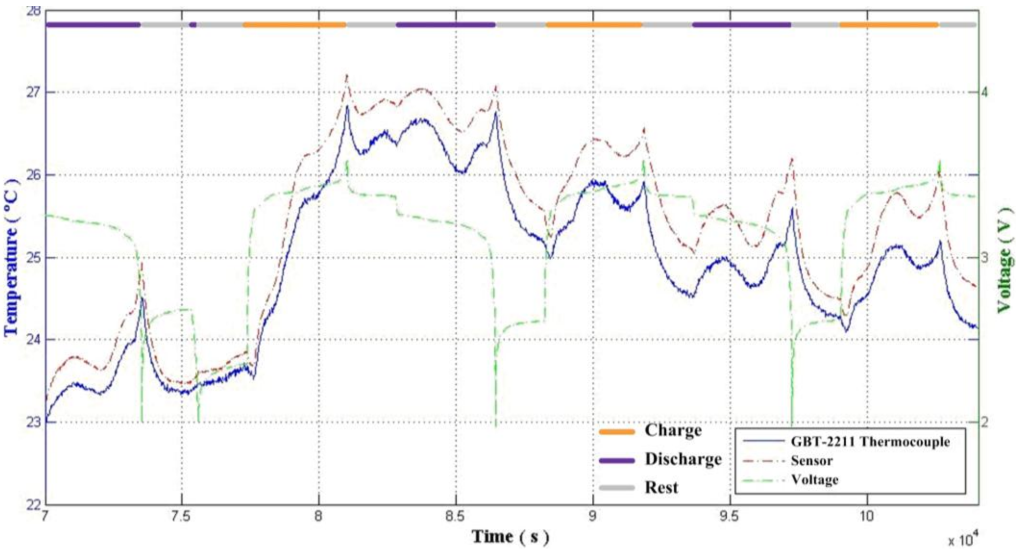

Figure 10. Temperature curve during 1/2C charging and discharging.

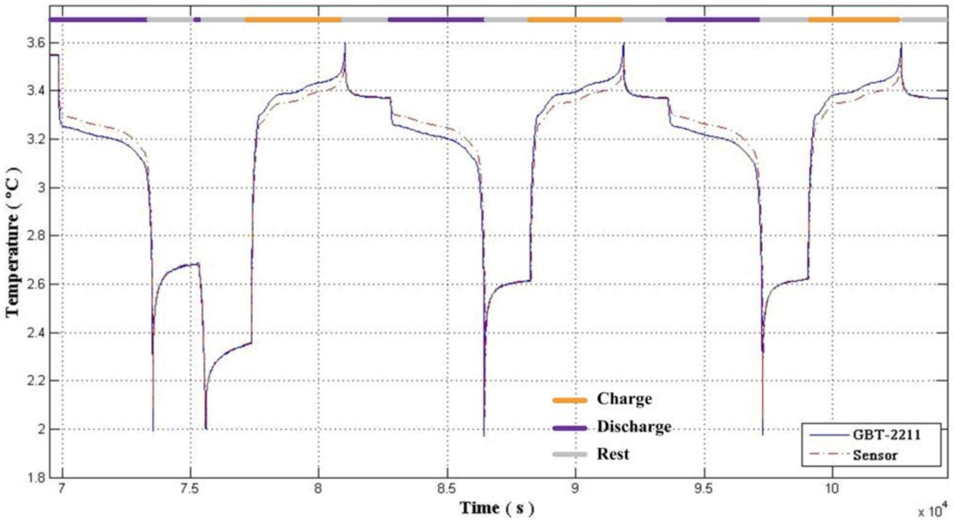

Figure 11. Voltage curve during 1/2C charging and discharging.

5. CONCLUSIONS

In this work, a micro temperature and voltage sensor was successfully fabricated by the micro-electro-mechanical systems (MEMS) process for integration on a flexible film substrate. Flexible micro temperature and voltage sensor can be embedded into lithium-ion battery to acquire in situ temperature and voltage data. These data are useful for improving the safety of, and conducting research into, lithium-ion batteries.

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