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Integrated microsensor for real-time microscopic monitoring of local temperature, voltage and current inside lithium ion battery

Chi-Yuan Lee [a,*], Shuo-Jen Lee [a], Yi-Ming Hung [b], Chien-Te Hsieh [b], Yu-Ming Chang [a], Yen-Ting Huang [a], Jyun-Ting Lin [a]

[a] Department of Mechanical Engineering, Yuan Ze Fuel Cell Center, Yuan Ze University, Taoyuan, Taiwan, ROC
[b] Department of Chemical Engineering & Materials Science, Yuan Ze University, Taoyuan, Taiwan, ROC

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ABSTRACT

The lithium ion battery overcharge may cause thermal runaway, even hazardous conditions like explosion, resulting in safety problem. High charge/discharge rate is required for 3C products like smart phone and tablet PC and electric vehicles, but it will cause steep rise of internal temperature of lithium ion battery, unstable voltage and current and safety problem.

This study used micro-electro-mechanical systems (MEMS) to develop an integrated microsensor of temperature, voltage and current microsensors, embedded in the lithium ion battery for real-time microscopic monitoring of internal temperature, voltage and current. This integrated microsensor is characterized by quick response, real-time measurement and batch manufacturing.

1. Introduction

The greenhouse crisis made various countries reduce carbon emission actively. The U.N. adopted the “United Nations Framework Convention on Climate Change (NFCCC)” at the UN Headquarters in New York in May 1992 to make a global control target agreement for the emission of anthropogenic greenhouse gases to buffer climatic warming. The ‘Kyoto Protocol’ was adopted in Japan Kyoto in 1997, subscribing the future greenhouse gas emission goals of industrial countries. However, Taiwan’s energy power generation in the next 10 years is confronted with the operation of new nuclear power plants and the decommissioning of old nuclear power plants, with the Fukushima event, the operating condition of new nuclear power plants has become the focus of all circles in Taiwan. Therefore, while the fossil energy cost increases continuously, it is an important way out to look for probable new energy actively.

The traditional lithium ion battery is used in portable electronic equipments extensively, such as notebook computer, mobile phone and electric vehicles. However, the lithium ion battery has several defects, including expensive sealant, explosion caused fire and electrolyte leak [1]. The lithium ion battery using liquid electrolyte has a serious problem, the dendritic lithium crystal is likely to cause explosion [2,3]. The electrolyte of lithium ion battery can be mixed with additives to improve the battery safety and enhance the battery capacity and service life. For example, the fire-retardant additive contributes to incombustibility or flame resisting of electrolyte, but too much addition of fire retardant can influence the electrical property of battery, so the consumption of fire retardant shall be considered [4]. Zhu [5] indicated Bis (2,2,2-Trifluoroethyl) ethylphosphonate (TFEP) as conventional fire-retardant additive to enhance the safety of lithium ion battery. When 20% TFEP was added in, the electrolyte was not ignited, meaning TEFEP has excellent fire retardance, and it is a new high efficiency safe additive. In addition, the insulated overcharge additive can be used, when the battery is overcharged, the anode oxidizes, the oxide is diffused to the cathode and reduced to neutral molecule till the charge stops. The insulated overcharge additive covers the product of polyreaction on the anode surface to interrupt the anode overcharge [6]. Garay [7] measured the change in the apparent resistivity distribution characteristic of materials in lithium ion battery. Galobardes [8] proved that the SEI could be used as the protective film for the anode of lithium ion battery. Pomerantseva [9] indicated that the internal stress of battery electrode in the discharging/charging process was related to the reliability and cycle life of lithium ion battery. Mutyala [10] used thin film thermocouple for lithium ion battery temperature monitoring. Lithium-ion batteries with different applications in industries need to be safe, reliable and long-lasting energy storage systems. The internal tem-

* Corresponding author. Postal Address: Department of Mechanical Engineering, Yuan Ze University, 135 Yuan-Tung Road, Chungli, 320 Taoyuan, Taiwan, ROC.
E-mail address: cylee@saturn.yzu.edu.tw (C.-Y. Lee).

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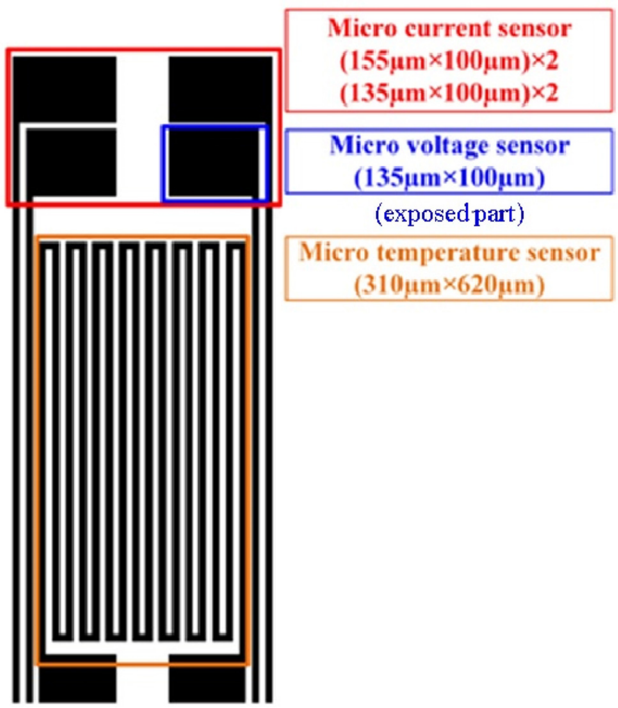

Fig. 1. Design drawing of integrated micro sensor.

perature of the battery, which is higher and more critical compared to the surface temperature, can be affected by internal thermal failures. Hence, internal temperature estimation and fault diagnosis is necessary for lithium-ion batteries to avoid the problem of overheating. Luenberger observer is designed to detect and isolate three main thermal failures in the battery, consisting of thermal runaway, convective cooling resistance fault, and internal thermal resistance fault [11]. A distinct asymmetry between charging and discharging is revealed which results from the intrinsic asymmetry of the reversible heat as well as differences in the kinetic limitations of the lithiation and delithiation of active materials [12].

Lee [13] had been developed a novel integrated two-in-one flexible micro sensors are fabricated using the micro-electro-mechanical systems (MEMS) process for in-situ monitoring of temperature and voltage in a coin cell. In this study, a new integrated microsensor of temperature, voltage and current microsensors, embedded in the lithium ion battery for real-time microscopic monitoring of internal temperature, voltage and current.

2. Principle and design of integrated microsensor

2.1. Micro temperature sensor design

The micro temperature sensor is a resistance temperature detector (RTD), and its electrode takes a snake shape. Its sensing principle is as follows: when the ambient temperature rises, due to the positive temperature resistance coefficient, the resistance of the RTD will also see increase. The relation between change in the ambient temperature and change in measured resistance can be expressed by equation (1):

$$R_t = R_r(1 + \alpha_1 \Delta T) \quad (1)$$

where R_t is the resistance at T°C, R_r is the resistance at reference temperature, α_1 the temperature resistance coefficient, and ΔT the temperature difference. The design shown in Fig. 1.

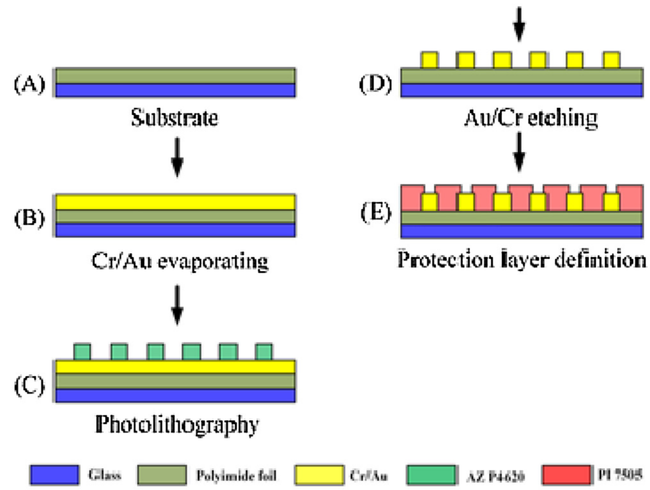

Fig. 2. Production process of integrated micro sensor.

2.2. Micro voltage sensor design

The size of the micro voltage sensor developed in this study is designed as 135 μm × 100 μm, as shown in Fig. 1. Only the frontmost probe is exposed, the other part is covered with insulating material. The sensing principle is that the analyte is given a firm power, then the voltage difference between two probes is measured.

2.3. Micro current sensor design

The sensing principle of the micro current sensor developed in this study is that the current value of analyte can be obtained by using Ohm's law V = I × R. The design is shown in Fig. 1. The micro current sensor comprises four miniature probes, including a set of (2) voltage measuring probes and a set of (2) resistance measuring probe, the sizes are 135 μm × 100 μm and 155 μm × 100 μm respectively. Only the frontmost probe is exposed, the other part is covered with insulating material, connected to measuring instruments to measure the voltage difference and resistance.

3. Process of integrated micro sensor

This study used surface micromachining technology of MEMS manufacturing technology to develop integrated micro sensor. Fig. 2 shows the integrated micro sensor process, (a) the 50 μm thick polyimide foil (PI foil) is used as substrate and soaked in acetone (CH_3COCH_3) solution, shaken by ultrasonic oscillator, soaked in methanol (CH_3OH) solution, and the surface is cleaned with DI water, then it is taken out and baked; (b) in this study, EBS-500 E-beam evaporator machine of Junsun technologies company is used. The E-beam evaporator deposits a 500 Å thick chromium thin film as the adhesion layer between Au and PI foil, then the 2500 Å gold thin film is deposited; (c) the spin coater (WS-400B-6NPP, Laurell Technologies Co.) spin coats positive photoresist (PR) uniformly, and the aligner (AG-200-4N-D-SM, M & R Nano Technology Co.) and mask define the pattern for photoresist, then the required pattern is developed by developer; (d) the unwanted metal film is removed by commercially available Type-TFA Au wet etching solution and Cr-7T Cr wet etching solution, the photoresist film is removed by acetone after etching; (e) polyimide film (DURIMIDE® 7505) is used as the insulating and protective layers of integrated micro sensor. The complete structure layer test strip once again be photolithography process and is placed on the rotary coater base in the same three-stage speed (1000 rpm–1500 rpm–3000 rpm) coated.