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Thin – Film Thermocouple Sensor Development for Smart Battery Cells

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Summary:

Smart battery cell concept, cells with integrated sensors, becomes more important as battery manufacturer tend to manufacture larger capacity packs to meet electrification demand. In order to accomplish smart cell concept in battery cells first step is accurate perception of battery states. However, conventional sensors are not able to measure parameters precisely. Furthermore, these bulky conventional sensors add significant weight resulting in significant loss in energy/kg density, thereby limiting the feasible quantity and therefore spatial coverage. This study presents a thin-film temperature sensor designed for battery monitoring. A thin layer (total <150 nm) of Alumel & Cromel (K-type thermocouple) are sputtered onto a newly developed TECASUB PEEK LDS (Polyether ether ketone). The sensor was tested externally on cylindrical cell and successfully capture temperature gradients with 1C cycling test.

Keywords: Thin – film, Flexible Sensors, Sputtering, Temperature Sensing, Smart Batteries

Background, Motivation an Objective

Batteries are being pivotal part of net-zero society. However, increasing prevalence of batteries highlights their safety problem for example China experienced an average of seven EV fire incidents per day in the first half of 2022 [1]. Moreover, this trend is likely to increase as vehicle manufacturers move towards longer range, larger vehicles, requiring higher capacity packs. Early fault detection mechanisms are essential to prevent cell failures becoming catastrophic. Current pack topologies, trade-off sensor deployment with cost, typically resulting in one or two temperature sensors per module (12 – 16 cells). This sparse configuration causes inefficient management of battery cell resulting with premature degradation & safety issues.

To minimise potential safety hazards and increasing efficiency of batteries, we propose smart cell, cells integrated with sensors and circuitry. At laboratory scale, integrating sensors within a cell has been demonstrated [2], its practical application is hindered by conventional, bulky sensors, which significantly increase the weight of the battery pack & inability to be implanted within the construction of the cell for more fast and accurate measurement.

Thin – film sensor technology offers promising solution for this field – principally films can be deposited on a range of substrates, including flexible materials. Their minimal size, high precision and fast responses make them ideal candidate for battery applications. Current state-of-art blends flexible substrates with off-the-shelf sensors, for example Vincent et al. embedded a thermistor film array inside a cylindrical cell to measure core temperature [3]. Challenges such as corrosive environment, potential negative effect on battery performance (capacity loss, necessity of cell modification post-manufacture).

In this study, a novel thin – film temperature sensor was developed with Polyether ether ketone substrate and manufactured by DC sputtering. The sensor was wrapped around cylindrical cell (Molicel P45B 21700, 4.5 Ah) for preliminary testing to verify sensor and concept design for further sensor implantation into cell.

Materials & Method

Due to its application requirements temperature sensor must be resilient & fast. The sensor will be placed into a cell to observe the gradient between core and external; minimal fluctuations in temperature may help identify degradation, critical to provide an early indicator of failure. Fundamentally, thin-film thermocouples are fast response, reliable and present minimal electrical interference compared to alternative options (thermistors, RTDs etc.). As a passive component, thermocouples which do not need any external excitation to measure temperature, which is crucial to ease applications in batteries.

Sensor Fabrication & Testing

The sensor was fabricated using DC magnetron sputtering (Korvus HEX Magnetron Sputtering System) onto a TECASUB LDS film (Ensinger GmbH, 0.1 mm). A three leg thermocouple design (3 sensing points, located 15mm apart) was selected to observe axial thermal gradient.

Prior to sputtering active materials, a 30 nm thin layer of titanium was sputtered onto substrate to enhance bonding between sensor and polyimide. Then, 90 nm cromel and 100 nm alumel layers were sputtered respectively to build sensor, following by annealing at 200 °C for 6 hours to strengten bonding.

Subsequent fabrication, sensor was wrapped around the external of a cylindrical cell with K-Type reference thermocouples (RS 363 - 0250) for proof of concept. Shown in Figure – 2.

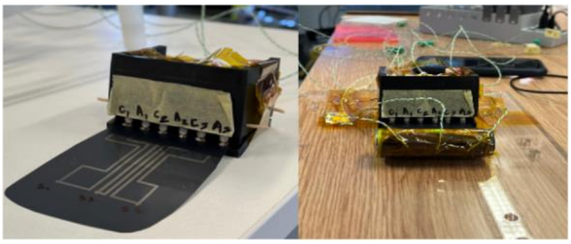

Figure 2 Thin-film sensor and experiment setup on cylindrical cell with reference thermocouples

Post instrumentation, the cell was tested under various battery cycling regimes (housed within a climate chamber at 25°C) to observe sensor reliability and response magnitude. Commercial thermocouples were placed on cell surface to validate temperature reading, Figure – 3.

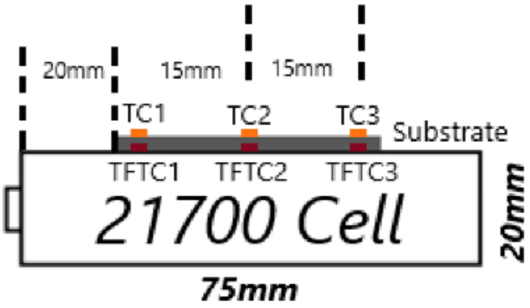

Figure 3 - Layout of thermocouple sensing points.

Measurement was conducted by using data acquisition system (NI 9212 DAQ and 9718 Chassis) configured to record voltage output with acquisition rate of 1s and 1ms respectively. The voltage values were converted to temperature via thermocouple table lookup interpolation.

Results and Discussion

The thin-film sensor successfully tracked temperature during two cycling regimes (firstly 1C with 30-min rest, Figure 4, and secondly 1C with 2-hr rest, Figure 5). The fabricated sensors typically demonstrated good performance (TFTC1 shown here), within +/- 0.5 °C of the reference thermocouples, considering manual sensor alignment. Peak temperature of ~11°C above baseline was recorded at the end of each discharge cycle, aligning with values recorded in prior studies [2]. Baseline drift was observed highlighting the necessity of improved cold junction compensation (CJC) in the aquistion system. Nevertheless, thin – film sensor prominent candiates for smart cell concept.

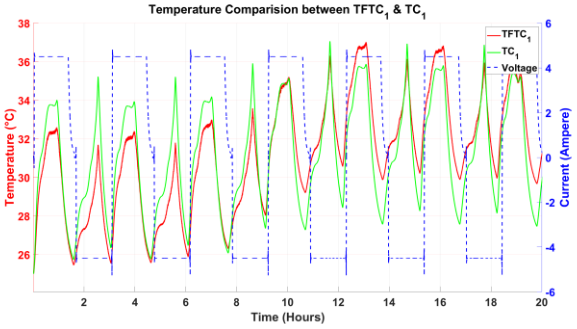

Figure 4 Temperature Value of First Cycling (Red: Thin-Film Thermocouple, Green: Reference)

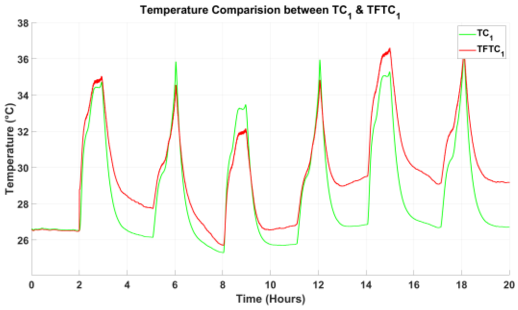

Figure 5 Temperature Value of Second Cycling (Red: Thin-Film Thermocouple, Green:Reference

Future work will involve optimising measurement setup accounting for CJC, and sputtering a novel ceramic coating onto the sensor to prepare the sensor for direct insertion into the cell, to achieve fast and reliable temperature data acquisition. Overall, this study successfully developed a thin-film thermocouple on a novel substrate with an integrated connection mechanism.

Acknowledgements

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