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Imaging thermal gradients on a Li-ion battery cell during operation using frequency-domain phosphor thermometry

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Abstract: Phosphor thermometry is applied on a mechanically loaded Li-ion pouch cell battery during operation. Using an optimised frequency domain method. Temperature images were obtained with a precision better than 0.1°C, revealing thermal patterns on the battery during charging and discharging. © 2024 The Author(s)

1. Introduction

Thermal management of electrochemical batteries is necessary because any deviation from the permissible temperature range can accelerate battery ageing or even lead to thermal runaway. The thermal behaviour of batteries must be characterised through temperature imaging to design appropriate cooling strategies. IR thermography was performed on single battery cells, revealing striking spatial dynamics during the discharging process [1]. However, in a stack, battery cells behave differently than single cells due to the battery casing, which ensures a controlled preload force and prevents uncontrolled expansion. This condition also ensures the thermal insulation between battery pairs, imposed by symmetry. Therefore, in this study, we propose to explore the thermal behaviour of a pair of pouch Li-ion cells, which are mechanically loaded by a thermally-insulating glass plate, representative of its mechanical and thermal conditions in real operation. To image the temperature, a 2D phosphor thermometry technique is considered. One key advantage of phosphor thermometry here is that it is based on excitation and detection of visible light, so the battery surface can be imaged through an inexpensive and low-conductivity glass plate, unlike infrared transmissible plates used for infrared thermography. In view of thermal management, the aim is to bring temperature differences across the battery in high-load operation to below 5 °C. Therefore a method with a high temperature resolution is necessary. For this reason, we implement a frequency domain phosphor thermometry method. Under temporally modulated excitation, the luminescence emission waveform is phase shifted with respect to the excitation due to the finite luminescence decay time of the phosphor. This method is applied here to a pouch cell stack to explore its thermal dynamics, at different State of Charge (SoC), during charging and discharging.

2. Experimental methods

The phosphor YAG:Cr³⁺ was used for those measurement. Under blue excitation, its red luminescence emission has a characteristic decay time which is 1.8 ms at room temperature and decreases at a rate of 1.1 %/K. The choice of the excitation waveform (square waveform at 100 Hz) is the result of a recent parametric study [2]. The coating was excited by blue LEDs, whose modulation frequency is limited to 1 kHz. To exploit phosphors with shorter decay times, diode lasers are needed as in [3]. For the 2D imaging, the phosphor's luminescence was detected by a high speed camera, recording at 10,000 frame per second. The battery was coated with a 10-20 μm layer of phosphor mixed with binder, and a preload force was applied on the cell surface by the borosicate glass plate, as shown in Fig. 1.

3. Results and Discussion

An example of temperature image obtained on the battery is shown in Fig. 1 at 10 % SoC during the discharging process at 3.5 times the nominal current. The image consists of 120 x 120 independent measurements, with a spatial resolution of 1.2 mm x 1.2 mm per measurements. Although the temperature difference across the whole battery is only 4°C, thermal gradients are clearly visible, owing to the high level of precision of 60 millicelsius, as determined under isothermal conditions (battery at rest for 24 hours). As shown in Fig. 1, the battery temperature

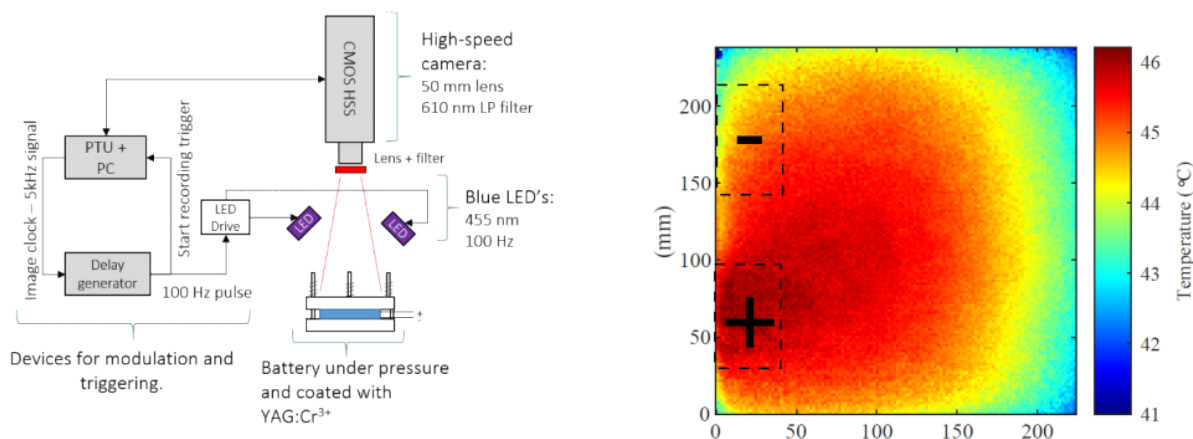


Fig. 1. Experimental setup to apply frequency domain phosphor thermometry on the mechanically preloaded Li-ion battery cell in operation (left), temperature field measured on the battery during discharging at 3.5 times the nominal current for a state of charge of 10% (right)

reaches locally above 40 °C at the end of the discharging process. The temperature is lower near the negative electrode, made of copper, due to its higher thermal conductivity and lower ohmic resistivity than the positive aluminum electrode.

The phosphor coating was also found not to suffer from ageing under repeated cycles, and measurements performed after the battery was left at rest for 24 hours, indicated a maximum deviation of 0.5 °C to measurements from a thermocouple placed on the positive electrode. Full results are presented in an upcoming article [4].

4. Conclusions

This study demonstrated that the temperature distribution on the battery during charging and discharging can be assessed under well defined electrical, mechanical and thermal boundary conditions and a precision of 0.1 °C. These measurements can now be utilised with inverse heat transfer methods to determine the spatial distribution of heat generation on the pouch cell battery, which is crucial to develop better models, as well as to design the battery thermal management system. The temporal resolution was 0.25 s, which was sufficient to probe the slow thermal changes on the battery. To achieve higher temporal resolution, faster phosphor such as $\text{ScVO}_4:\text{Bi}^{3+}$ [5], and diode laser modulated at frequencies above 100 kHz as in [3] will be considered.

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