Thermal Characterization of a Fiber Bragg Grating Sensor Array for Measuring Absolute Surface Temperature on a Pouch Cell

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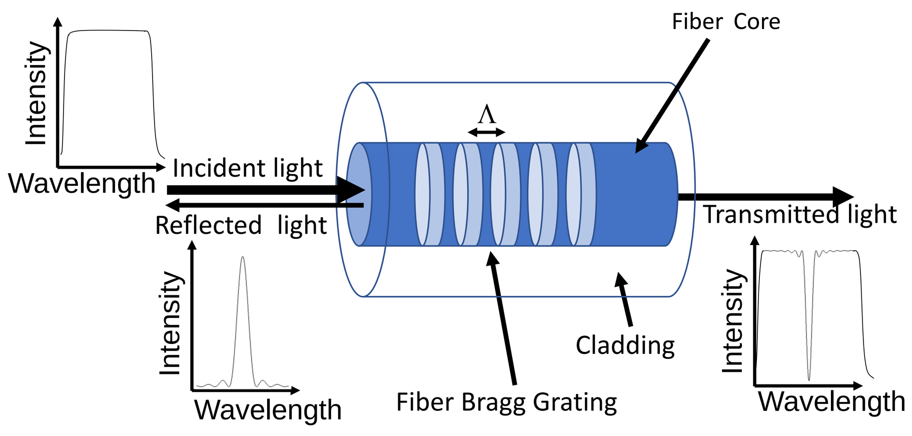
Introduction

Thermal monitoring of a lithium-ion pouch cell is essential for safe use.[1] Until now, the temperature has only been monitored at a few preselected points in a battery module and passed on to the battery management system (BMS). The BMS controls the operation of all the cells in a battery pack. It prevents over-charging, over-discharging, over-heating. However, single point measurement cannot fully represent the thermal state of all cells. Additional sensors are needed. Fiber Bragg grating (FBG) sensors are promising candidates for such sensors because they are immune to electromagnetic interference, are small and lightweight, and perform well in harsh environments.[2] Other advantages of FBGs include the ability to multiplex (inscribe more than one FBG into one fiber each with different Bragg wavelengths), and their sensitivity to more than one parameter, such as temperature and strain. In this work, we use a fiber optic sensor with 9 FBGs inscribed to **monitor the surface temperature** of a lithium-ion pouch cell.

Fiber Bragg Grating

Figure 1 shows the operating principle of a fiber Bragg grating. Broadband light propagates through the fiber core and a certain wavelength is reflected at the grating. The grating is a modulation of the refractive index of the core produced by irradiating the fiber with intense laser light. The reflected wavelength can be calculated with equation 1[3].



$$\lambda_B = 2 * n_{eff} * \Lambda \qquad (1)$$

Figure 1: Principle of an FBG sensor

External factors, such as temperature, strain and humidity, can influence the grating period (Λ) and the effective refractive index (n_{eff}) and thus influence the grating reflected wavelength (λ_B). To use the fiber as a sensor, prior calibration is required.[2,3]

Temperature Calibration

For temperature calibration, we use the setup shown in figure 2a. It consists of an aluminum heat spreader in a climatic chamber in which the fibers and the reference sensor are installed. At each calibration point, the temperature is assigned to the measured reflected wavelength. Each temperature is kept for at least 45 min to ensure thermal equilibrium. Two resulting calibration curves are shown in Figure 3a. The orange curve is the calibration curve when the relative humidity is not kept constant in the climatic chamber and the green curve is the calibration curve at a constant relative humidity of 50%. The hysteresis in the orange curve is due to the changing relative humidity when heating/cooling the climatic chamber.

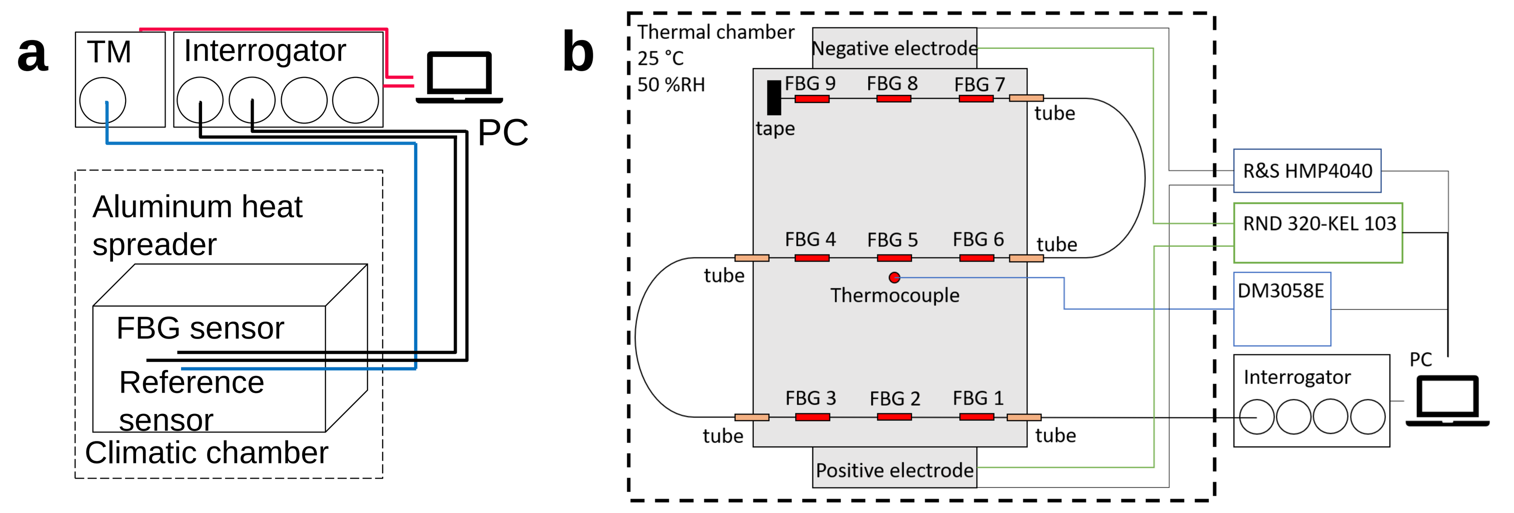


Figure 2: a) Calibration setup, TM Thermometer T4200 from Dostmann electronics, FBG interrogator si155 from Luna Inc. b) Surface temperature measurement on a pouch cell, R&S HMP4040: power supply, RND 320-KEL 103: DC electronic load, DM3058E: Digital Multimeter

Contrary to the manufacturer's specifications, the influence of relative humidity on the fiber with polyimide coating cannot be neglected and has to be taken into account.[4] Therefore, the relative humidity must be kept constant during calibration, figure 3.

Literatur / Zitat

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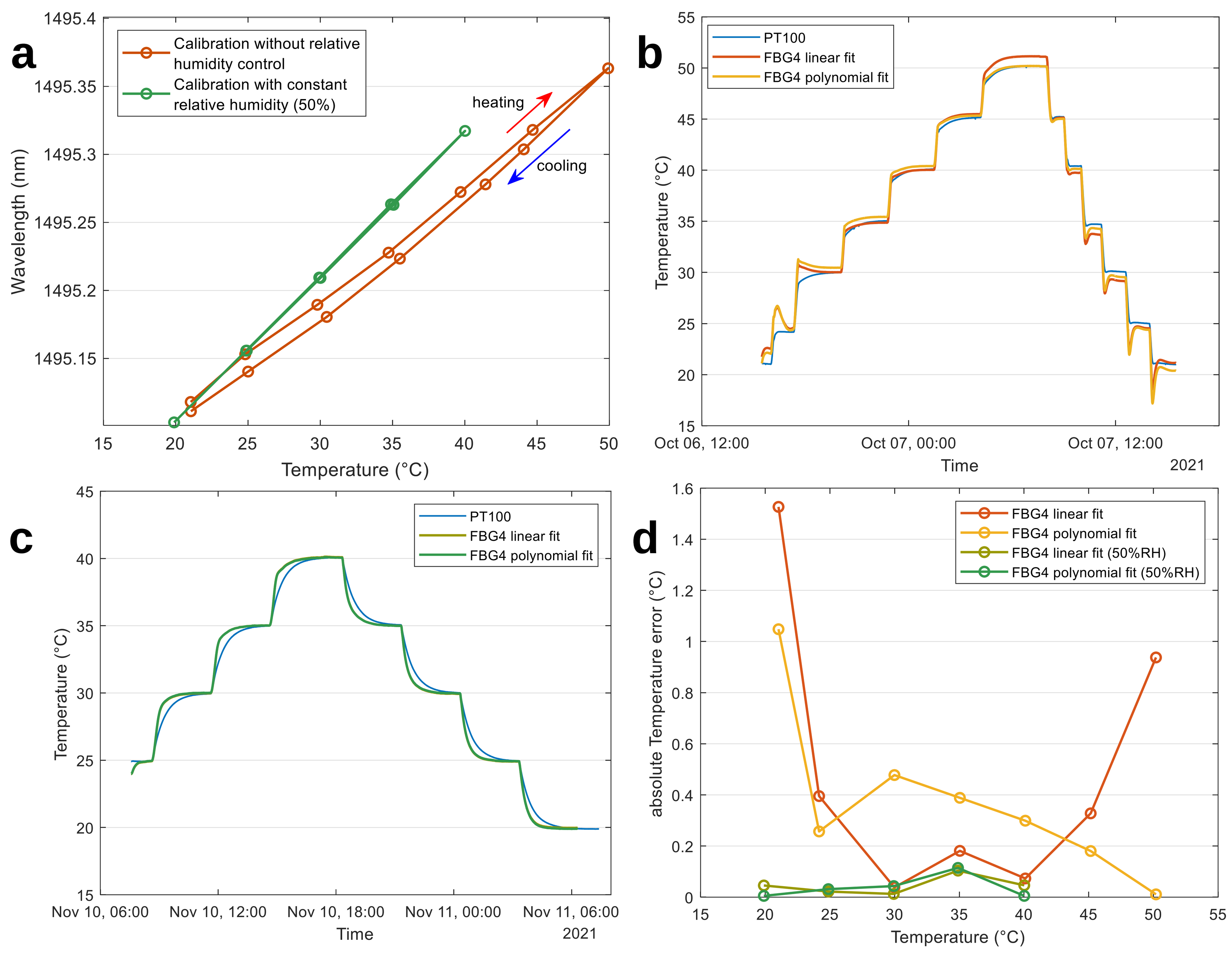

*Figure 3: Improvement of the calibration when relative humidity is considered: **a)** Calibration curve for the calibration without defined relative humidity (orange) and with constant relative humidity of 50% (green), the wavelength accuracy is 1 pm and the temperature accuracy 15 mK **b)** temperature calculation with linear fit and polynomial fit of the orange calibration curve in **a**, Spikes: The climatic chamber was set to a higher/lower temperature then needed to heat/cool the aluminum heat spreader faster and the FBGs already reacted to that temperature and the PT100 sensor not. **c)** temperature calculation with linear and polynomial fit of the green calibration curve in **a**. **d)** absolute calibration temperature error for the different fitting curves.*

Surface temperature

FBGs were mounted on the lithium-ion pouch cell with tubes guiding the fiber, figure 2b. At the negative electrode the fiber was fixated with a tape. With the tubes the fiber can move freely and no strain is applied. The measured temperatures are shown in Figure 4 top. The measurements were done in a climatic chamber at a temperature of 25 °C and a relative humidity of 50%. The pouch cell was discharged with **3 different C-rates**. The temperature profiles look the same for every discharge rate and match the control measurement with the thermocouple. However, the temperature increases with increasing C-rate.

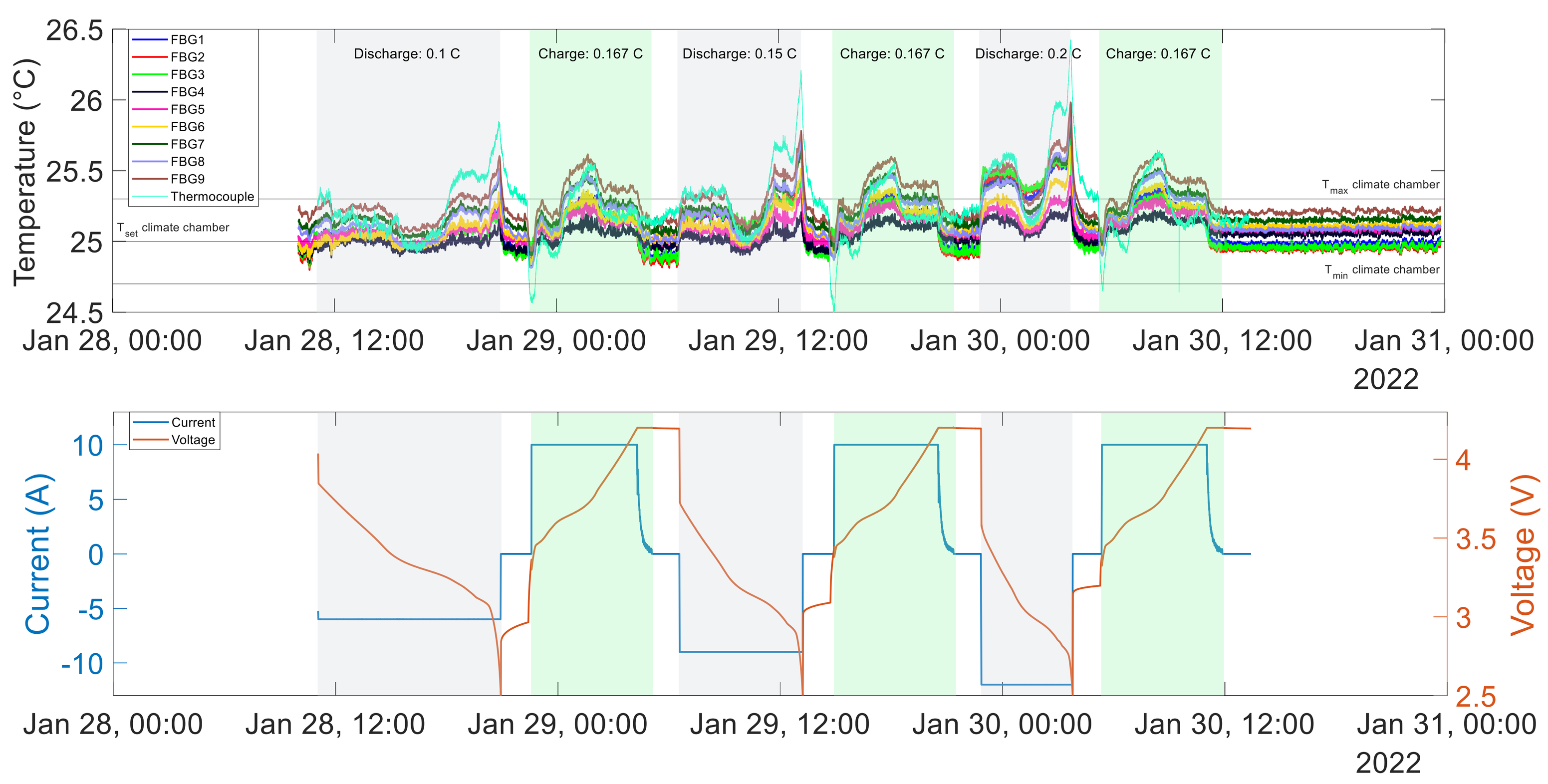

Figure 4: Surface temperature (top) of a pouch cell at 9 points during discharge (0.1C, 0.15C, 0.2C) and charge (0.167C) and the voltage and current profile (bottom).

Conclusion

An FBG sensor array for monitoring the surface temperature of a lithium-ion pouch cell is demonstrated. The calibration of the sensor is shown in detail. The polynomial fit is better than the linear fit. However for the calibration with constant relative humidity both fitting methods are equally good. The **maximum calibration error** for the linear fit is up to **1.53°C** when relative humidity is not kept constant and **1.05°C** for the polynomial fit. For a calibration with constant relative humidity the calibration error decreases to **0.11°C** for the linear fit and **0.10°C** for the polynomial fit. The 9 FBGs measure the surface temperature with high accuracy.

Project partners:

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