Webinar Q&A
Monitoring Cell Temperature to Optimize Battery Performance and Design
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What is the measurement uncertainty of fiber optics compared to typical values of RTD or thermocouples? What is its working range?
The measurement uncertainty of RTD is very small, on the order of 0.1-0.2°C whereas for thermocouples, it's 1-2°C. The fiber sensors' measurement uncertainty in the range of battery testing is similar to thermocouples. The temperature range of the standard sensors are -40°C to 200°C for HD-FOS and -40°C to 120°C for packaged FBGs.

What is the maximum temperature that the optical sensor can withstand?
The commercially available sensors are rated to 200°C for long-term use. Custom sensors are available for use up to 500°C. Both of these sensors can be taken up to higher temperatures (published results have gone up to 900°C) but only for very short durations.

For cell temperature monitoring, is there any risk of the high temperature melting the fiber optic? What is the temperature limit of the FBG?
Standard HD-FOS sensors are rated to 200°C on top end while a standard FBG sensor is rated to 120°C on the top end.

Is there a solution for installing sensing fiber for temperature distribution measurement up to 800C?
The commercially available sensors are rated to 200°C for long-term use. They have been used to higher temperatures for short bursts of time. The sensor does not start to physically change (the glass starts to soften and anneal) until it approaches 600°C through long exposures to these temperatures.

Is it possible to record both strain and temperature simultaneously on an ODiSI?
It is possible to record strain and temperature on separate channels of an ODiSI, but not as 2 outputs from a single ODiSI channel.

Is a fiber optic sensor sensitive to external applied pressure?
The fiber sensor is not sensitive to external applied pressure e.g. when put through a pressure feedthrough. The fiber sensor has been used in autoclave applications of a few thousand psi.

What is the minimum distance between two measured points along the fiber optic sensor?
For HD-FOS, the minimum distance between 2 points is 0.65 mm.

With using an FOS cable with the Hyperion, how many measurement points could be taken inside a battery assembly?
The number of gratings that can be written into an FBG string ranges from 20 to 80, depending on the temperature range required for each sensor.

Can you distinguish changes in temperature vs strain or do they interfere with each other?
The fiber sensor doesn't distinguish between temperature and strain inputs, and responds to both. These inputs are therefore decoupled by sensor selection and installation. For temperature measurements, fiber sensors are housed in a tube (PTFE for standard HD-FOS temperature sensors). For strain measurements, a bare fiber is bonded down to the substrate. For thermal compensation of strain measurements, 2 measurement channels can be used on an ODiSI, 1 for strain and 1 for temperature compensation.

The results of the temperature measurement based on the distributed optical system is a relative temperature. How would this be converted to absolute temperature?
The measurement from an external measurement e.g. from a thermocouple or RTD at the start of the test can be applied to the fiber measurements to convert to absolute temperature.

What is the composition of fiber optic sensors? Are they placed inside fiber optic cables or on the outside?
These fiber sensors are made from doped silica. They are polymer-coated. The HD-FOS sensors are simply packaged as connectorized and terminated sensors on a spool. The FBG sensors are packaged into transducers (see www.lunainc.com for different sensor options).

Can fiber optics be made by 3D printing or printable electronics methods?
I have seen some work on 3D printing fiber preforms but am not familiar with how far along those are on the development path. If considered simply as light guides, there are also efforts in the silicon photonics side to convert optical fiber into waveguides on chips.

For sensing using FBGs, are the fibers classical single mode fiber or microstructured fiber for enhanced sensitivity?
HD-FOS sensors are single mode fiber with a polyimide coating. FBG sensors have gratings written at specific locations in the core.

Is there any special material required to attach the fiber optic sensor around the cells, without affecting the readings?
For strain measurements, a foil gage epoxy such as MBond 200 can be used. For temperature measurements, tape or putty can be used.

Which kind of tubes are you using to protect/cover the FBGs?
The FBGs are typically housed in are housed within a sealed, alumina ceramic tube.

What fixative are you using to build the temperature pads?
The fiber is held between 2 pieces of Kapton sheets in a predetermined layout.

Are you using HD-FOS only for surface measurements or battery core temperature measurements too?
The measurements presented in the webinar were from surface measurements, but it is also possible to embed sensors directly in the jelly roll or pouch cell.

How would you insert an optical fiber sensor into a battery cell? How would you ensure sealing or resealing without damaging the fiber sensor?
We have previously placed the fiber sensor inside lithium ion batteries (cylindrical cells and pouches). The fiber measurements aren't affected by the current because the fiber is non-conductive (made of glass). We did not have issues around the sealing process for the pouches and cells that we were using.

Can your sensors be used in cylindrical, pouch (prismatic) cells? Or are the sensors better suited to one type specifically?
The sensors would be suitable for both. We have previously integrated the fiber sensor inside both cylindrical cells and pouches. And we have used them on modules built from either cylindrical or pouch cells.

How does this technology respond to vibration?
The Hyperion is suitable for vibration-intense environments due to its high acquisition rate (maximum of 5kHz). The ODiSI is more suitable for static applications, though it has been used in vibration-intense applications such as heating chambers, autoclaves, and moving vehicles to make measurements from slowly changing parts.

What is the diameter of the sensor? How would you protect the fiber sensor from damage?
The fiber sensor outer diameter is 165 µm. For embedded applications, the sensor ingress and egress locations are the primary high stress locations that require protection, perhaps using putty or tubing. For surface-mounted sensors, the sensor placement should be pre-designed such that free fiber loops are minimized to minimize the chance of the sensor being accidentally snagged. The best way to protect sensors is to pre-assemble them into temperature pads in the layout of interest as shown in the presentation, protecting the fiber leads with PTFE tubing.

What analysis methods are commonly used to determine optimal sensor placement?
To measure every cell in a module or pack, we have seen customers place the sensor to touch each terminal as these typically get hotter faster. To measure temperature distribution for packaging design variation, this will probably be driven by the CAD / FEA folks.

What is the measurement principle behind each mm of the fiber having its own spectra?
The measurement method behind the ODiSI is a combination of Optical Frequency Domain Reflectometry (OFDR) along with Swept Wavelength Interferometry (SWI).

How does the backscatter amplitude affect your detection performance of the correlation-based temperature/strain retrieval?
The Optical Frequency Domain Reflectometry (OFDR) along with Swept Wavelength Interferometry (SWI) methods used for the high definition distributed sensing ODiSI make use of detection schemes that measure the output from the interference between the backscatter and the incoming laser. This ensures sufficient amplitude for signal detection.

I typically build the data acquisition into my systems. How can I do that with the fiber sensors? The processing of the fiber signals seems to be done with preconstructed units. Is there a feasible circuit approach to embed this within my own design?
We have some R&D projects based around integrating the data acquisition into the customer's native system. It is possible but does require some overhead. The more straightforward approach would be to integrate the measurement output from the ODiSI or Hyperion into the native data acquisition systems.

Does the data acquisition system support real-time data logging for control purposes?
ODiSI data can be logged in real time or streamed to a client using the ODiSI Measurement Streaming Protocol (OMSP), which consists of JSON-formatted data sent over a TCP/IP connection. Programs can be written to further manipulate this data stream for viewing, logging, and control. A similar principle is true for the Hyperion.

Can the sensors be integrated with wireless communication to transfer data to the BMS?
The fiber sensor uses laser light as the signal carrier and as such needs to be physically connected to the laser source within the interrogator. The processed data (in the form of temperature) can then be transmitted wirelessly to a second platform.

Are the measurements with fiber optics consistent or does it need regular calibration throughout its life cycle?
The measurements are consistent throughout cycling. Calibration is handled 2 ways: the interrogator contains an internal gas cell calibration for the laser while the sensor is pre-calibrated for taking the spectral measurements into the temperature or strain space.

I assume the cost of the interrogation unit is higher than an EV so integration of the technology with an EV may not be practical. Could you speak to that?
Active and real-time measurement using this technology is most suited for R&D applications where engineers and designers are trying to optimize designs. For on-board applications, this again might be suitable in the design and validation phase. Once it comes to regular operation, the suggestion is for sensors to be embedded and intermittently interrogated e.g. as part of an improved efficiency charging station. This is one way to address the practicality aspect.

How does optical sensing compare from a cost point of view to other options available?
The optical sensing systems become cost competitive when there is a need for multiple sensors, especially alongside a tight space requirement.

Is your fiber optic sensing technology being used currently by OEMs or is it yet to enter the marketplace?
The Hyperion and ODiSI platforms as well as sensors are available as released products, that are currently being evaluated by OEMs for individual applications.

Has there been any HD-FOS integrated inside any battery configuration to improve the resolution?
The HD-FOS system is being evaluated for integration primarily as part of the design process.

What are the general applications of FBGs?
Our website contains more information on FBG applications (http://www.micronoptics.com/products-applications-1/). Examples include security (perimeter sensing), energy (power plant and wind turbine blade monitoring), and civil (bridge and dam health monitoring).

Why use more expensive fiber optics over conventional measurements that use electrical signals that perform well enough? What is the real benefit?
Fiber sensors come in handy for applications where there exist challenges when using conventional electrical sensors e.g. spaces where the system is electrically active, contains EMI fields, requires high measurement density and multi-sensor counts, and requires efficiently multiplexed sensors due to space constraints. It is an additional tool in the measurement toolbox.

Can I get a copy of the slides and webinar recording?
Both the slides and webinar recording are available here: https://lunainc.com/monitoring-cell-temperature-optimize-battery-performance-design-webinar-resources-page/