Fiber-optic temperature measurement solves HV challenges in e-mobility

Tech Article

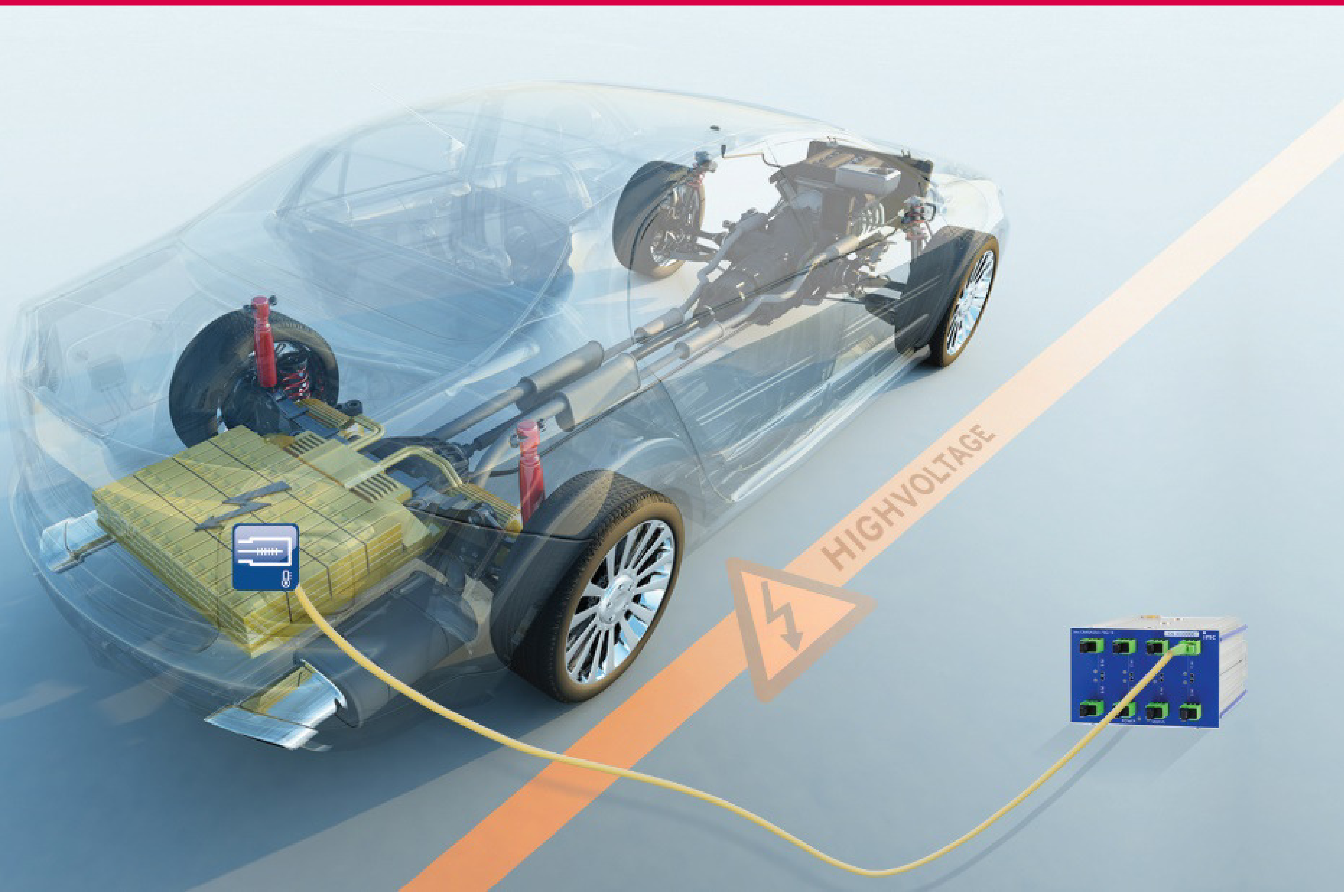

Figure 1:
Consistent isolation of the HV environment using FBG technology avoids additional safety measures, qualification requirements and costs. (©iStock.com/Firstsignal, imc)

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In product development and verification of typical mechatronic applications, temperatures are still among the most important process variables. To acquire these, test engineers use traditional electrical sensor types such as thermocouples, RTDs (PT100/1000) or NTCs. These have become established and have been safely mastered for decades. However, the current upheavals in vehicle construction – keyword e-mobility – are increasingly calling this established approach into question.

New concepts with sensors based on fiber-optics with interference filters (fiber Bragg grating or "FBG"), on the other hand, meet the new requirements of high-voltage environments. Thanks to their purely optical measuring principle, they offer a perfect isolation concept against high voltage and are completely immune to electromagnetic interference. These advantages point to questions of handling, occupational safety and liability, which present users with unexpected challenges in the development and production of electric drive trains.

What special training and equipment does the personnel involved need during setup and operation if the cables can be under dangerous voltage when using conventional electrical measurement technology? Can a manufacturer completely instrument entire units such as battery packs as test specimens and how can they protect themselves against the fact that these cannot simply be deactivated? How are special cables extended? These technical, organizational and also legal questions can be defused or even completely avoided by the use of fiber-optic measurement technology.

Measurement principle behind the sensor

The physical principle of FBG sensors is based on a glass fiber in which an optical grating is engraved. This is done by means of an high-energy fs-laser which manipulates the refractive index of the material in the actively sensitive area at precise intervals. In measurement mode, “white” light fed into the fiber from a broadband laser source is selectively reflected at this interference grating. The narrow spectrum returned by the sensor represents the measured variable corresponding to the characteristic Bragg wavelength λ_B. It is proportional to the strain and temperature of the fiber, because these determine the optical grating intervals.

The challenge in sensor development is now to clearly separate these two influencing variables. For strain sensors (“optical strain gauges”), this means compensating for the influence of temperature. In temperature sensors, the fiber may only react to the inherent temperature expansion α (T) and the refraction behavior of quartz glass as function f(T). Therefore it needs to be embedded stress-free in order to avoid the influence of external expansion or mechanical tension.

The specially developed FBG sensor technology offered by imc achieves this by encapsulating the fiber in a glass capillary with a diameter of only 0.51 mm. Versions with additional ceramic and Teflon coatings are mechanically even more robust and yet only enlarged to 1.0 and 1.5 mm. The extremely small design and minimal thermal mass ensures a correspondingly fast response speed with time constants of around 100 ms. Such extreme dynamics are relevant for start-up tests on electric motors. Thus, these processes can be systematically monitored in order to fully understand and optimize them.

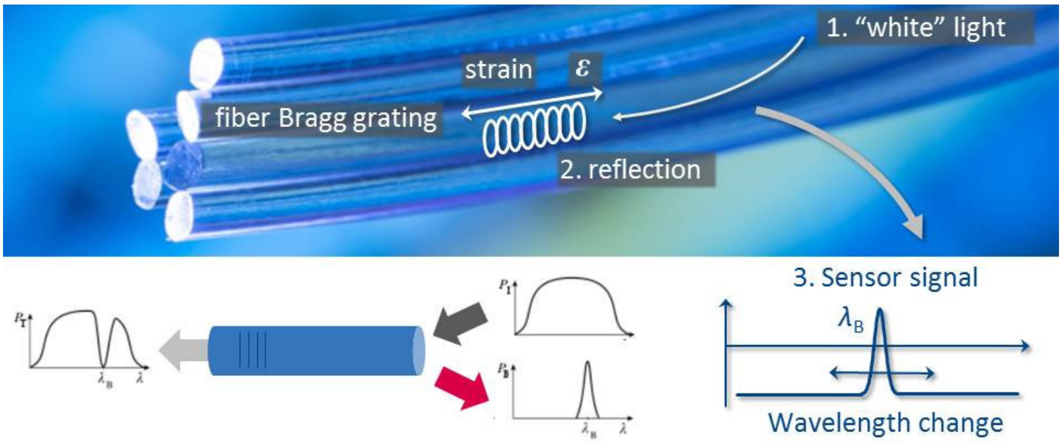


Figure 2: FBG sensors: The fiber Bragg principle (©iStock.com/kynny, imc)

Analysis method of the measurement device

To determine the Bragg wavelength of the acquired spectrum, evaluation units, also known as interrogators in FBG technology, use various methods. Some measurement devices work with the traditional spectrometer method. As a characteristic parameter, the maximum (peak) of the spectrum is determined by means of a high-resolution measurement along the wavelength. In practice, these meters are relatively bulky, energy-hungry, not very robust in terms of the operating environment and, not least, very expensive.

The FBG module from imc, on the other hand, is based on an innovative approach. It measures the intensity in conjunction with an “edge filter”. This color filter, comparable to a frequency high-pass cut-off filter, attenuates the overall signal along the linear or exactly known filter characteristic. The measured intensity corresponds to the integrated narrow-band spectrum of this reflected and filtered signal. The change in intensity allows detection of the exact shifting of the Bragg wavelength along this filter characteristic.

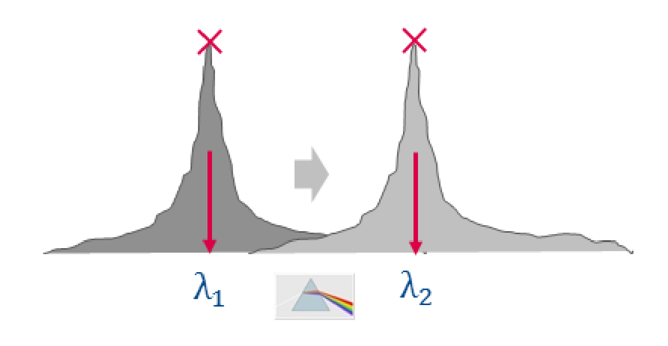
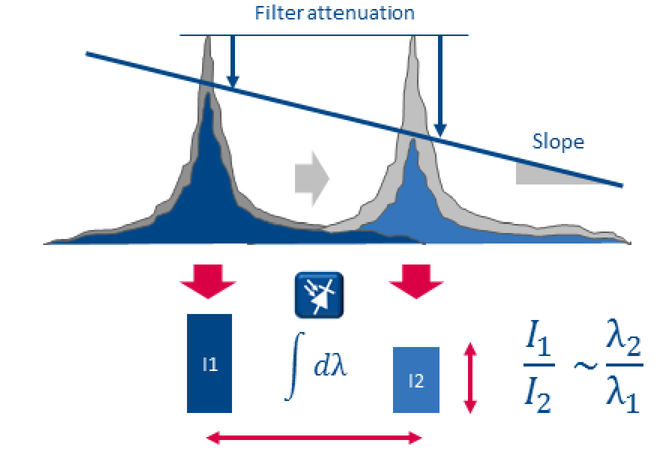
	**Spectrometer** Peak detect (Spectrum) λ (peak)
	**Cut-off filter (edge filter)** Intensity measurement Integrated photo detector Relative intensity drop (slope)

Figure 3: FBG analysis principles: Spectrometer vs. edge filter (©imc)

Finally, a ratiometric assessment is carried out: The relative ratio of filtered and bypass raw signal I_0 is examined. As a result, general transmission losses in the fiber or fluctuations of the laser source intensity do not have any effect.

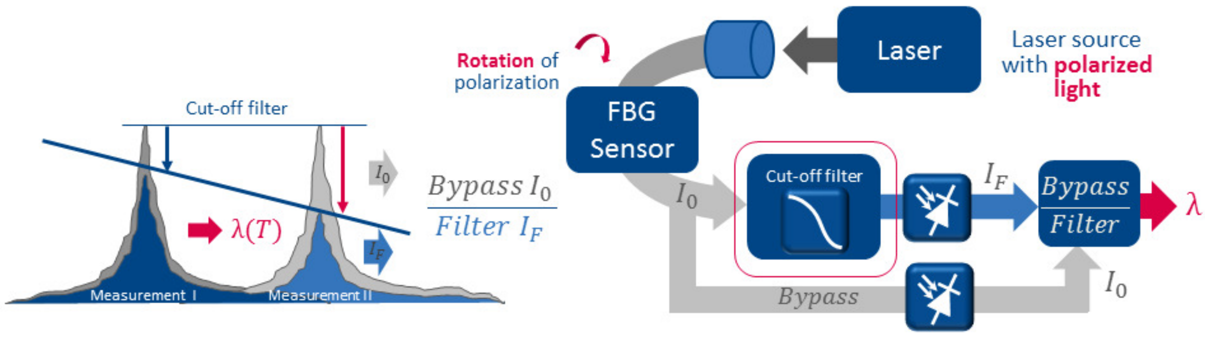


Figure 4: Ratiometric method independent of intensity attenuation (©imc)

This concept enables a very compact, robust and portable design of the measurement device. Opto-electronic chips integrate the optical components of the splitters, switches and filters together with photodiodes for intensity acquisition in the smallest of spaces. The subsequent electrical signal conditioning, AD conversion, and digital signal processing maps the process with corresponding characteristic curves and compensation algorithms, and finally results in direct temperature readings. In this way, the fiber-optic measurement device achieves the price level and ease of handling of conventional HV measurement technology.

Integration into a standard mechatronic measurement system

The fiber-optic measurement module is equipped with a CAN interface that delivers the digital result data. In testing environments of test benches and mobile driving tests, the CAN bus is widely used as a universal bus system – both as a source of additional measurement and process variables supplied by control units (ECU) that need to be synchronously acquired, and also as a system bus for networking measurement modules and data loggers. With the *flex* series, the test and measurement equipment provider imc has developed a modular system in which the housings of measurement and digitizing modules (imc CANSAS*flex*) as well as suitable CAN bus data loggers (imc BUSDAQ*flex*) can be docked together to form blocks. The units formed in this way are both mechanically and electrically coupled, in terms of power supply and CAN bus “backbone”, both of which are directly through-connected. This allows the user to flexibly assemble a customized measurement system within seconds to meet the current requirements of the testing application with its sensors and signal sources. The 8-channel FBG module for imc CANSAS also fits into this concept and extends the possibilities to the domain of fiber-optic measurement technology. This is particularly important for the e-mobility and automotive fields. The newly emerging measurement points on HV components with their special requirements have to be recorded and correlated together with a multitude of other sensors, signals and ECU process variables.

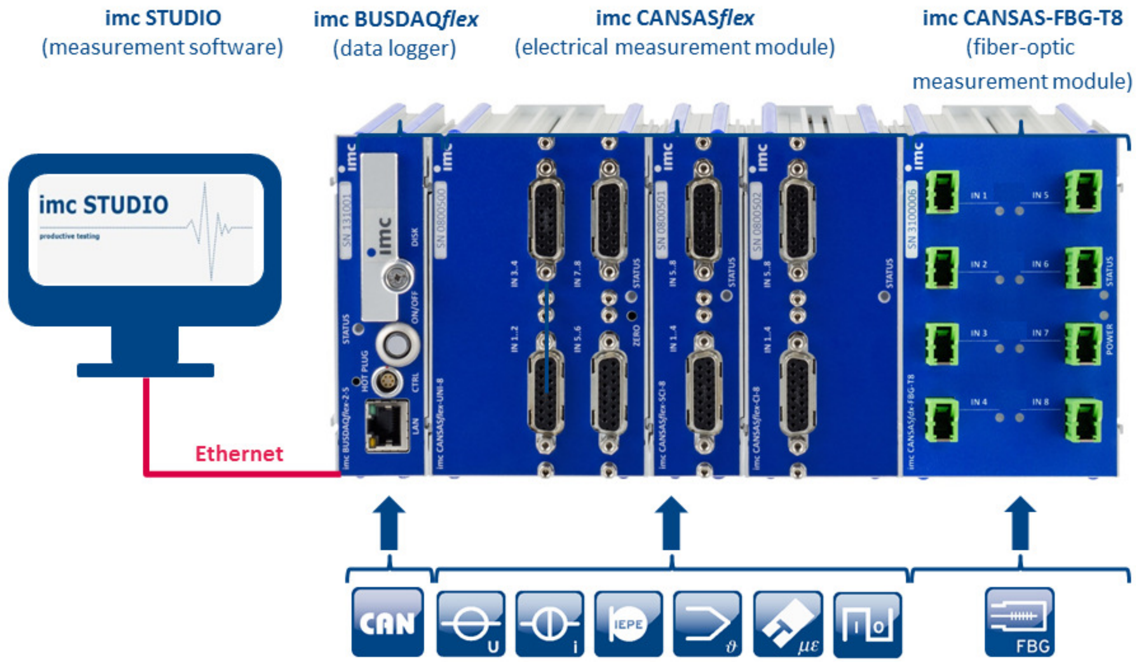


Figure 5: Integration into universal CAN-based measurement system for mechatronic testing (©imc)

In practice

The capabilities of fiber-optic measurement systems are many and diverse, with the field of e-mobility being one of the major and fastest growing applications. This is not limited to cars only, but it also applies to the electrification of agricultural machines and their previously hydraulically operated work implements. In addition to battery systems, many of their components and subsystems need to be developed and tested, such as charging infrastructure, cable harnesses, power electronics modules, connectors, etc.. The inherent EMC robustness of FBG technology also opens up new areas of application, such as the direct measurement of temperatures inside the windings of electric motors. Developers of power inverters or power electronics, like those with new wide-bandgap semiconductors and modern inductive components can also benefit from the miniaturized and highly dynamic sensors in their development tests: Temperature profiles of power electronic components under load can be acquired without the results being affected by drastic electromagnetic interference fields.

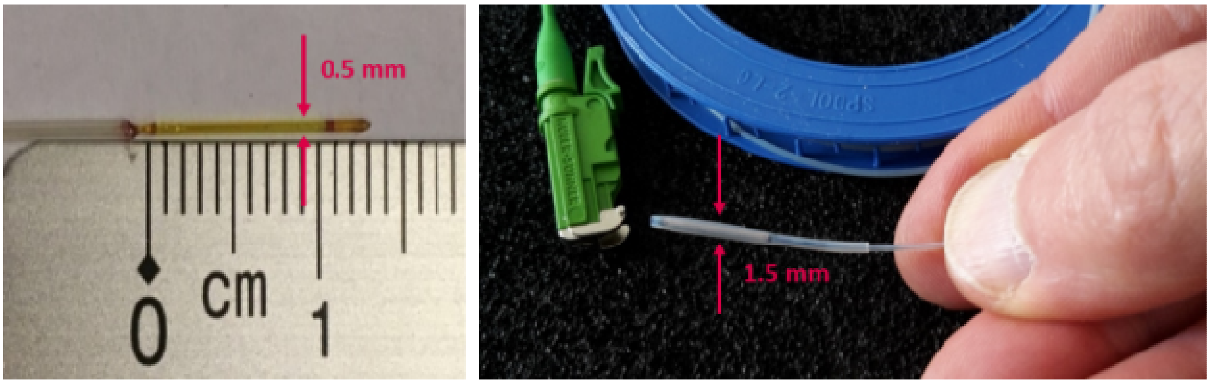


Figure 6: Miniaturized, highly dynamic and metal-free sensors (©imc)

Conclusion

The measurement approach with mixed optical and electrical technology solves many difficulties in the area of handling and personnel safety. By completely separating the hazardous HV environment from the operator and measurement systems through purely optical transmission, FBG measurement technology can increase productivity and efficiency. This applies both to the product under investigation and to the test processes themselves.

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