EM CLAIMS THE BRAGGING RIGHTS

Nanomaterials physicist **Diandra Leslie-Pelecky** believes EM Motorsport has a lot to shout about with an exciting new sensor that could change the way we go about our business

IN 1912, the Braggs (William Lawrence and his father, William Henry) discovered a fundamental law of diffraction that paved the way for hundreds of technological innovations from basic physics to gemstone identification. Little could they have known that, 100 years later, one of those applications would form the basis of an innovative new sensor that could be about to make a big impact on the motorsport scene.

BELOW CDs and DVDs (right) have different diffraction patterns because of the different sizes of the pits on their surfaces

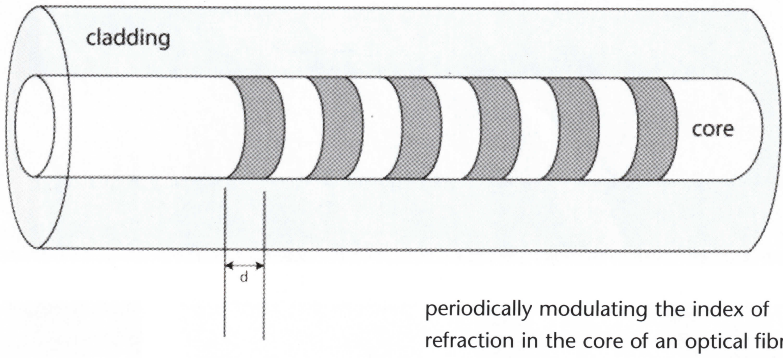
It all comes down to a simple observation. Any electromagnetic wave incident on a material experiences one (or more) of three processes: reflection, refraction or transmission. What the Braggs discovered was that these behaviours can combine to produce a unique effect when the material contains a regularly spaced array of objects, separated by a distance comparable to the wavelength of the light.

This discovery wasn't entirely new, however. Diffraction from periodic arrays on surfaces had been known since the late 1700s, and the chances are you've witnessed it recently – the rainbows produced by CDs and DVDs, for example, are due to light diffracting from the periodic pits etched into the discs' surfaces. These occur because the pit dimensions – 1.6 microns for CDs and 0.74 microns for DVDs – fall close to the wavelength of visible light (0.4 to 0.8 microns) and cause the white light to diffract into its component colours.

The Bragg experiment – diffracting x-rays from the regular spacing of atoms in a crystal – showed that diffraction could occur in the *bulk* of a material as well as on the surface. Modifying any property of a material in a periodic way changes how the light will interact with the material.

A material's *index of refraction* tells you how much that material decreases the speed of light relative to its speed in vacuum. Glass, with an index of refraction of 1.5, slows light to two-thirds its speed in vacuum. Optical fibres consist of a glass core surrounded by a cladding. The cladding has a lower index of refraction than the core, which constrains the light to travel only within the core. Light can travel large distances relatively undisturbed through optical fibres, making them ideal ways of transmitting information.

In the 1970s, scientists discovered that



periodically modulating the index of refraction in the core of an optical fibre (above) selects out a particular wavelength of light. Such a structure is called a Bragg Fibre Grating (BFG). Light sent through a BFG will mostly travel through unimpeded; however, light of a wavelength λ will be reflected instead of passing through the fibre if it satisfies the condition:

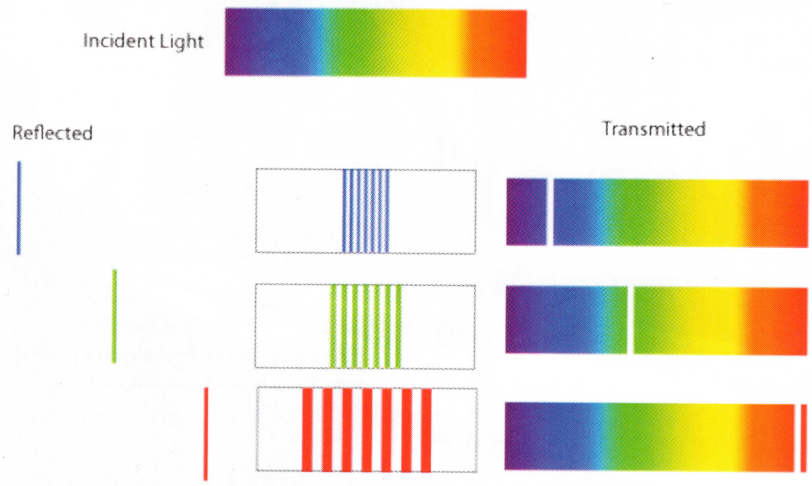
$$\lambda = 2nd$$

where n is the index of refraction and d is the array spacing. You can select which wavelength of light is treated differently by changing the array spacing, as illustrated schematically, right. Conversely, measuring the wavelength of the reflected light thus allows one to determine the array spacing.

Although arrays can be manufactured with different spacings, anything that changes array dimensions – for example, strain or expansion due to change in temperature – also changes the wavelength of light returned, making the BFG a sensitive means of measuring both temperature and strain.

And this is where we get back to motorsport. BFG sensors have been available for structural applications like monitoring bridges for decades, but they've never previously been developed into a

BELOW It's possible to select which wavelength of light is treated differently by changing the array spacing



> ***"This sensor requires thinking outside the traditional scope of motorsport engineering – but the rewards could be profound"***

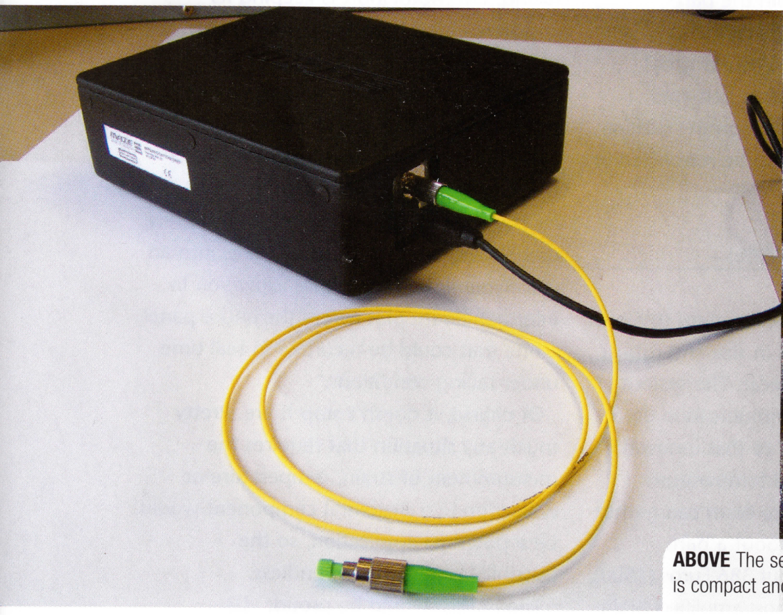
form suitable for use in motorsport. Now, however, EM Motorsport has developed a way to make them, in the words of EM Motorsport general manager Stephen Watt, "motorsport proof".

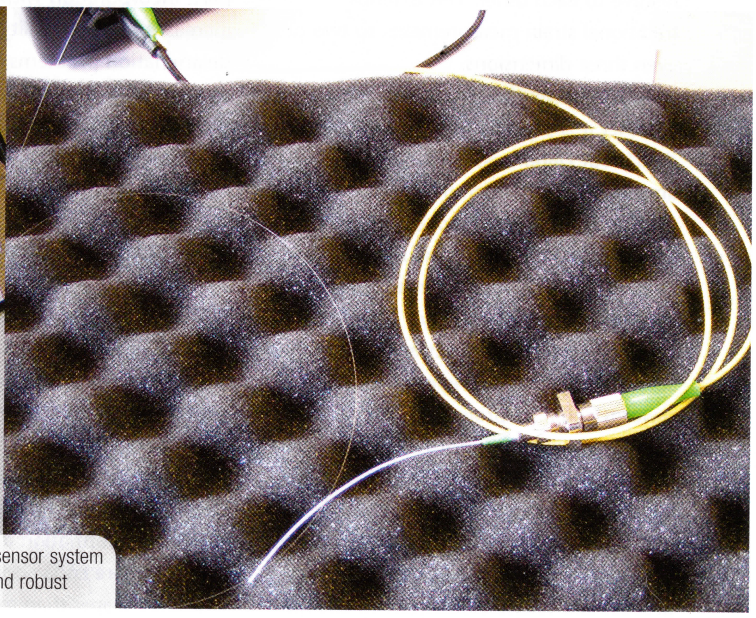
Of course, there are other ways to measure strain. A traditional strain gauge is simply a patterned piece of thin metal foil that changes its electrical resistance as strain is applied. It's a very simple solution, but the resistance changes are modest and hence limit you to using small voltages. The resulting amplification requirements and susceptibility to electrical interference limit the sensitivity and applicability of these devices.

The BFG-based sensor developed by EM Motorsport solves these issues. It uses optical measurements to determine how each sensor array spacing is modified by strain or temperature change, and the lack of electrical measurement makes the BFG immune to electromagnetic and radio frequency interference. However, there have still been barriers to overcome. EM Motorsport technical director Vaifro Dariol notes that the primary challenges in applying BFGs to motorsport have been threefold: firstly, writing arrays in optical fibres economically, precisely, and without degrading the mechanical properties of the fibre; secondly signal processing; and, thirdly, the job of miniaturising and ruggedizing the components.

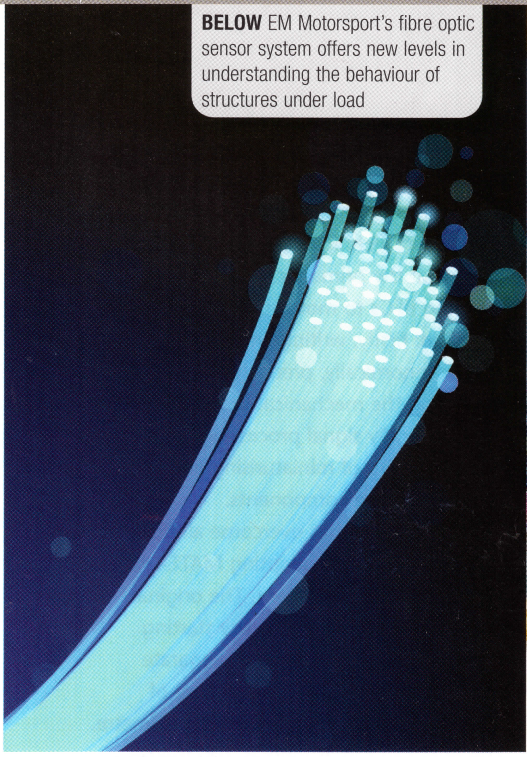
EM Motorsport has overcome all three of these challenges by adapting MATE-LAB's Fibre Optic Sensor System. The original MATE-LAB system was the key starting point, offering as many as 80 separate sensors within a single optical fibre of diameter less than a quarter of a millimetre. The fibre can run as long as 100 metres – or even kilometres if the application allows a large distance between sensors. MATE-LAB provides the versatility of a made-to-order sensor system coupled with the ability to permanently incorporate the sensors in carbon fibre components during fabrication. This technology offers new opportunities to track component behaviour not only across spatial dimensions, but also over time.

For example, Watt notes that aerodynamic testing of wings often employs a handful of traditional strain gauges; however, if a wing is used and returned to the wind tunnel for testing, measurement reproducibility is subject to placement accuracy and gauge-to-gauge reproducibility. Instead of four or five ▶





ABOVE The sensor system is compact and robust



BELOW EM Motorsport's fibre optic sensor system offers new levels in understanding the behaviour of structures under load

BELOW The BFG sensors are likely to be utilised initially in aerodynamic testing

traditional strain gauges, EM Motorsport's system allows a team to place up to 80 BFG sensors on the same part. Because the BFG sensor can be incorporated permanently into the wing during fabrication, a team can track transient stress, as well as long-term flex from the cumulative impact of racing and testing.

A potentially more significant advantage is the ability to position the fibre in an 'S' shape to measure expansion and contraction by mapping sensor position relative to each other. This extends traditional strain measurements to two or even three dimensions.

> **"BFG sensors have been available for decades but never developed into a form suitable for motorsport"**

Motorsport engineers might question whether it is possible to have "too much data", but Dariol says that the large amount of information that can be collected with their sensor system can pose a challenge. "Engineers are used to working with a limited data set from a limited number of sensors," he says. "This sensor requires them to think out of the traditional scope of motorsport engineering – but the rewards could be profound." EM Motorsport sees its product as being useful for testing, and providing important information as input for race strategy.

Each sensor fibre is individually fabricated to customer specifications. A proprietary process allows EM Motorsport to custom write any combination of sensors in desired positions without significantly degrading fibre strength – absolutely necessary in the high-temperature, high-vibration environment of motorsport. Its process, Watt notes, produces strong enough fibres that the sensors outlasted some of the parts they were being tested on. An advantage of custom fabrication is that the cladding can be customized to make the sensor compatible with the specific types of resin that will be used in fabricating a part. Incorporation within the part increases reproducibility, eliminates delamination problems, ensures good contact, and provides measurements throughout a part, not just on the surface – although fibres may also be retrofitted to existing surfaces.

EXTENSIVE INFORMATION

LED lasers keep the optical system to about 10 cm x 8 cm x 2.5 cm in size and robust enough to use on a racecar. The system uses the same CAN communication used by most telemetry. Add to that innovations in signal processing and temperature compensation and a race team can gather extensive information about a part.

A single fibre costs about 386 Euros ($500), which is cheaper than most amplified strain gauges. The measurement unit costs about 10,000 Euros (depending on specifications), but can be used with two to three fibres. Watt notes that the EM Motorsport system may require more upfront investment; however, its system is certainly competitive with what teams currently spend for much less flexible sensor systems.

EM Motorsport's combination of precision strain measurements, customisability and ability to permanently incorporate the sensor within parts offers race engineers a challenge: consider not only changing *how* data is collected, but also *what* data is collected.

Because of the competitive nature of racing, EM Motorsport is keeping its customers (and their applications) close to the vest. But ponder a couple of the possible applications: a multi-sensor fibre embedded in a helmet or HANS device could be used to automatically forewarn rescue crews of impacts likely to have caused head or spinal injuries; alternatively, embedding an array of these fibres into an aerodynamic surface would allow you to infer a pressure plot across the entire panel – one that could be recorded in real time under racing conditions.

Of course, it doesn't stop there. Pretty much any situation that requires the measurement of strain, temperature or deflection in a structural component would be a potential application, so the possibilities are virtually endless.

The Braggs would be proud. RT