Microstructured fibers for sensitive strain transducers

Tadeusz Tenderenda, Michal Murawski, Michal Szymanski, Martin Becker, Manfred Rothhardt, Hartmut Bartelt, Paweł Mergo, Krzysztof Poturaj, Mariusz Makara, Krzysztof Skorupski, Paweł Marc, Leszek Jaroszewicz, and Tomasz Nasilowski

Bragg gratings fabricated in a photonic crystal fiber can function as extremely sensitive, temperature-independent strain sensors.

Optical sensors based on fiber Bragg gratings (FBGs) have gained popularity in recent years because their reflectivity spectrum is sensitive to temperature and stress. In addition to directly measuring strain and temperature, they also serve as the underlying technology for instruments that measure physical parameters such as vibration, displacement, moisture, and refractive index changes. This makes them attractive for a wide range of applications in medicine, biology, civil engineering, aeronautics, as well as the harsh environments of the oil, gas, and nuclear energy industries.

At the same time, the coincident influence of temperature and stress on the FBG spectrum can be constraining, as many applications require temperature-independent strain measurements. In such cases, the measurement system needs complex temperature-compensating mechanisms.

We show that the need for such compensation can be effectively eliminated by fabricating gratings in microstructured fibers (MSFs). By carefully designing the structures, we can increase their strain sensitivity by over two orders of magnitude compared to classical birefringent fibers. The technology could enable highly sensitive, temperature-independent strain transducers.

MSFs or photonic crystal fibers have been extensively studied for over a decade. While traditional fibers have a solid glass core surrounded by a solid glass cladding material, MSFs typically consist of a solid core and a cladding that contains a pattern of air holes that run along the length of the fiber, confining and guiding light (see Figure 1). Changing the topology and distribution of the air-hole pattern allows one to modify and tailor the fiber guiding and sensing properties. Reports show that MSFs can be used for various photonics applications, such as supercontinuum generation, fiber lasers, dispersion compensation, as well as for sensing. By properly aligning and spacing the air holes, the value of the pressure sensitivity $K_P$ in highly-birefringent (HB) MSFs can be increased nearly an order of magnitude in comparison to traditional HB fibers, and the value of the temperature sensitivity $K_T$ can be shifted to zero at desired wavelengths.

Our approach combines the mechanical sensing properties and temperature independency of MSFs with the sensitivity of fiber Bragg gratings. One recently reported dual-mode HB MSF is characterized by very high, controllable birefringence of the second order mode. As the maxima of the second order mode are closer to the hollow region of the fiber, they are subjected to higher strain distributions. This increases the polarimetric strain sensitivity of the second order mode to $4.94 \times 10^4 \text{rad/(strain \times m)}$ at $1.55 \mu\text{m}$, compared to $3 \times 10^2 \text{rad/(strain \times m)}$ for the fundamental mode. Further, since birefringence is introduced...
by air-holes instead of materials with different temperature coefficients, the dedicated fiber design keeps the polarimetric temperature sensitivity low for both propagated modes—5.8×10^{-2} rad/(K⋅m) for fundamental and 4.3×10^{-1} rad/(K⋅m) for the second-order mode.

More recently, we created FBGs in HB MSFs (see Figure 1) characterized by few-mode propagation.\(^1\) In birefringent fibers, unpolarized light yields two Bragg peaks (\(\lambda_1\) and \(\lambda_2\)), one for each orthogonally polarized mode. The peak separation is proportional to the phase modal birefringence. In few-mode HB fibers, each propagated mode is represented by such a dual-peak Bragg reflection. Figure 2 shows a typical spectral characteristic of one of our FBG samples. The temperature-independent strain response of such structures can be measured as the change of Bragg-peak-separation (phase modal birefringence) of a particular mode.

In practical applications, the measured signal can be transmitted to, from, and between the sensors by standard telecom SMF28 (Corning) fiber spliced to the measurement MSF. Furthermore, the proposed FBG-based sensor can be easily combined and multiplexed in multiple arrays, which allows the use of standard off-the-shelf components and interrogation units. We plan to test practical sensor applications in complex industrial environments with the goal of developing and commercializing the sensor technology.

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**Author Information**

Tadeusz Tenderenda, Michal Murawski, Michal Szymanski, and Tomasz Nasilowski
InPhoTech Ltd.
Warsaw, Poland

Tadeusz Tenderenda is a PhD student at the Institute of Applied Physics, Military University of Technology, Poland. Since 2011 he has been working as a research engineer at InPhoTech Ltd, a spin-off company focusing on research and technology transfer of specialty optical fibers, fiber sensors, and components.

Martin Becker, Manfred Rothhardt and Hartmut Bartelt
The Institute of Photonic Technology
Jena, Germany

Pawel Mergo, Krzysztof Poturaj and Mariusz Makara
Maria Curie-Sklodowska University
Lublin, Poland

Krzysztof Skorupski
InPhoTech Ltd.
Lublin, Poland

Pawel Marc and Leszek Jaroszewicz
Institute of Applied Physics
Military University of Technology
Warsaw, Poland

**References**


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