Multicore fibers for sensing applications

Abstract

Multicore fibers (MCFs) are optical fibers which have several cores integrated in a common cladding. As one type of space-division multiplexing, MCFs have been widely investigated in optical communication to improve the data capacity limit. Due to the intrinsic advantages such as small size, well defined core separation, improved isothermal behaviour, light weight, immunity to electromagnetic interference, MCFs have also attracted extensive interest for optical sensing. MCF based sensors can not only be utilized for structural health monitoring, but also medical sensing and robot position tracking. This thesis focuses on investigating and fabricating MCF based sensors with high performance by post-processing techniques such as inscribing gratings or introducing helical structures into the MCFs.

In this thesis, we first review the background knowledge of optical fiber gratings, optical fiber interferometry and MCFs, as well as the development of MCF based sensors. And then we detail the working principles, fabrication methods and experimental results of three sensors based on a heterogeneous MCF.

The first one is a directional bending sensor based on FBGs inscribed in the heterogeneous MCF. To date, several types of sensors based on FBGs inscribed in homogeneous MCFs have been reported. However, due to the homogeneous properties of the multiple cores, simultaneous interrogation of the FBGs in the multiple cores demands high precision and cumbersome alignment with, for example, a coupler and a ball lens, or customized and complicated fan-out devices. Therefore, to realize an easier interrogation of the FBGs in different cores, we propose to inscribe FBGs in heterogeneous MCFs. As the heterogeneous MCFs have non-identical cores, FBGs with different resonant wavelengths can be inscribed simultaneously into the multiple cores in only one process with the scanned phase mask method. The MCF we used has six identical outer cores and a center core with a little lower refractive index. Due to the difference in refractive indices between the center core and outer cores, the FBGs with obviously different central wavelengths can be measured by only splicing a segment of MMF between the MCF and the lead-in SMF. The curvature sensitivity of the FBG in the outer core depends on the bending orientation in the form of sine function. The maximum linear curvature sensitivity is about 0.128 nm/m^{-1}. The proposed sensor offers advantages of flexibility in fabrication, simple interrogation and capability of eliminating the cross sensitivity to temperature or externally applied axial strain.

The second one is a highly sensitive strain sensor based on a helical structure (HS) fabricated in the MCF. The MCF was locally twisted into a HS permanently by a CO_2 laser splicing system and then spliced between two short sections of multimode fibers (MMFs) to construct an in-line Mach-Zehnder interferometer. In the region of the HS, the outer cores were deformed into spring-like structures while the center core was kept straight. Due to the HS, a maximum strain sensitivity as high as −61.8pm/με was experimentally achieved. This is the highest sensitivity among interferometer-based strain sensors reported so far, to the best of our knowledge. Moreover, the proposed sensor has the ability to discriminate axial strain and temperature, and offers several advantages such as repeatability of fabrication, robust structure and compact size, which further benefits its practical sensing applications.

Based on the MCF with the HS, we also propose and demonstrate a sensor for directional torsion and temperature discrimination. By introducing the short HS, not only the fiber circular asymmetry was achieved but the multiple interference was enhanced significantly. The maximum torsion sensitivity of the proposed sensor reaches −0.118 nm/(rad/m) for the twist range from −17.094 rad/m to 15.669 rad/m. Compared with the previously reported torsion sensor schemes utilizing micro-machining means, the proposed sensor not only owns the capability of the discrimination of directional torsion and temperature but also takes the merits of easy fabrication and good mechanical robustness.

Publication list

Journal Papers Published

1. **H. Zhang** *et al*. Directional torsion and temperature discrimination based on multicore fiber with helical structure. *Opt. Express* **26**(1): 544-551(2018).
2. **H. Zhang** *et al*. Highly sensitive strain sensor based on helical structure combined with Mach-Zehnder interferometer in multicore fiber. *Sci. Rep*. **7**: 46633 (2017).
3. **H. Zhang** *et al*. Fiber Bragg gratings in heterogeneous multicore fiber for directional bending sensing. *J. of Opt*. **18**(8): 085705 (2016).
4. Z. Wu, P. P. Shum, X. Shao, **H. Zhang** *et al*. Temperature-and strain-insensitive curvature sensor based on ring-core modes in dual-concentric-core fiber. *Opt. Lett*. **41**(2): 380-383(2016).

5. Z. Wu, **H. Zhang** *et al*. Supermode Bragg grating combined Mach-Zehnder interferometer for temperature-strain discrimination. *Opt. Express* **23**(26): 33001-330072(2015).
6. R. Wang, R. Lin, M. Tang, **H. zhang** *et al*. Electrically programmable all-fiber structured second order optical temporal differentiator. *IEEE Photon. J.* **7**(3):7101510(2015).
7. R. Wang, M. Tang, L. Zhang, **H. Zhang**, *et al*. Demonstration of programmable In-Band OSNR monitoring using LCFBG with commercial thermal printer head. *IEEE Photon. J.* **7**(4): 6802008 (2015).

Journal Paper in preparation

1. **H. Zhang** *et al*. Spatial-division multiplexed helical long period gratings in multicore fiber for multiparameter measurement. (in preparation)

Conference Papers

1. **H. Zhang** *et al*. Helical long period grating in multicore fiber for simultaneous measurement of torsion and temperature. In *CLEO-PR/OECC/PGC* 2017.
2. **H. Zhang** *et al*. Directional bending sensor based on spatially arrayed long period gratings in multicore fiber. In *CLEO-PR/OECC/PGC 2017*
3. Z. Wu, **H. Zhang** *et al*. Sensing application based on helical-structured multicore fiber. In *CLEO-PR/OECC/PGC 2017*
4. Y. Zheng, Z. Wu, **H. Zhang** *et al*. Design of Fabry-Perot Refractometer based on a simplified hollow-core PCF with a CFBG pair. In *CLEO-PR/OECC/PGC 2017*
5. R. Wang, M. Tang, S. Fu, **H. Zhang** *et al*. Integrated chiral long period gratings in multicore fiber. In *CLEO*, May 2017, Paper JW2A.64.
6. **H. Zhang** *et al*. Simultaneous measurement of torsion and temperature based on helical structure in multicore fiber. In *ACP*, Nov. 2016, Paper AF3A-4. (OSA Best Student Paper Award).
7. **H. Zhang** *et al*. Highly sensitive strain sensor based on helical structure in multicore fiber. In *CLEO*, Jul. 2016, Paper SM2P.3. (IPS Singapore Chapter student travel grant award).
8. **H. Zhang** *et al*. Simultaneous measurement of temperature and curvature with multicore fiber based Mach-Zehnder interferometer and fiber Bragg grating, in *PGC*, Jun. 2015.
9. Z. Wu, X. Shao, P. P. Shum, **H. Zhang** *et al*. Grating effect in lanthanum aluminum silicate glass fiber，In *CLEO*, May 2015. Paper SM3L.2

10. Z. Wu, N. Zhang, P. P. Shum, X. Shao, **H. Zhang** *et al*. Curvature sensor based on long-period grating in dual concentric core fiber, In *CLEO*, May 2015, Paper ATu1M.5