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Application of Multi-core and Few-mode Fibre in Sensing Field

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Abstract: Space Division Multiplexing (SDM) technology based on multi-core fibre and few-mode fibre can significantly improve the transmission capacity of optical fibre communication system on the one hand; on the other hand, due to the different cores in the multi-core fibre and the different spatial modes in the few-mode fibre have different spatial distributions in the same fibre, these space division light field characteristics will produce different responses to the changes of the surrounding environment parameters. On this basis, the multi-core fibre and the few-mode fibre can be used to carry out more advanced sensing technology research. In this paper, a series of sensing technologies based on multi-core fibre and few-mode fibre are introduced, as well as the research progress of many new high-performance fibre sensors.

Key words: space division multiplexing technology, multi-core fibre, few-mode fibre, high-performance fibre sensor

1 Introduction

Space Division Multiplexing (SDM) technology based on multi-core fibre and few-mode fibre can significantly improve the transmission capacity of optical fibre communication system on the one hand; on the other hand, due to the different cores in the multi-core fibre and the different spatial modes in the few-mode fibre have different spatial distributions in the same fibre, these space division light field characteristics will produce different responses to the changes of the surrounding environment parameters. On this basis, the multi-core fibre and the few-mode fibre can be used to carry out more advanced sensing technology research.

As a global leader in optical fibre and cable industry, YOFC has been dedicated to the applications of high-performance specialty optical fibre in many fields. In recent years, YOFC has teamed up with the Optical Communications and Network Engineering Research Team of Huazhong University of Science and Technology to jointly do researches on SDM technology, and at the same time to carry out a series of sensing technologies based on multi-core fibre and few-mode fibre. By exploring the physical and structural characteristics of multi-core/few-mode fibre, a variety of new high-performance fibre sensors have been developed.

2 Research Progress of Sensing Technology Based on Multi-core Fibre

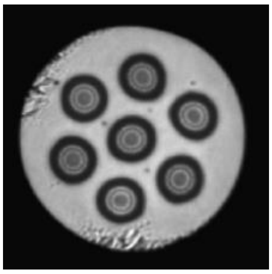


Figure 1 Sectional View of a Seven-core Fibre

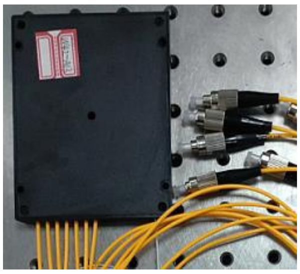


Figure 2 Seven-core Fibre Coupler

Various high-performance fibre sensors have been developed with high-quality multi-core fibre (note: fibre attenuation about 0.20 dB/km at 1550 nm, crosstalk is less than -40 dB/100 km, see Figure 1) and space division multiplexer/demultiplexer (note: insertion loss < 1.5 dB, crosstalk < -45 dB, echo reflection < -50 dB, see Figure 2) developed by the joint R&D team.

2.1 Multi-core Fibre Vector Bending Sensor

As shown in Figure 3, when Bragg Grating is ruled on different cores at the same location of the heterogeneous multi-core optical fibre, due to the difference in refractive indexes of the center core and the peripheral core, their Bragg coefficients are different. In order to measure the reflection results of the two different Bragg Gratings simultaneously, we use a multimode fibre to connect the core and a peripheral core of the multi-core fibre to the common single-mode fibre.

The test results show that the curvature coefficient of the Bragg Grating of peripheral core is sinusoidal of the bending direction angle of optical fibre. And because the coefficients of the center core and the peripheral core are different, the temperature change of the environment can be compensated by the center core. Finally, not only the curvature but also the bending direction of the optical fibre can be measured, as shown in Figure 4.

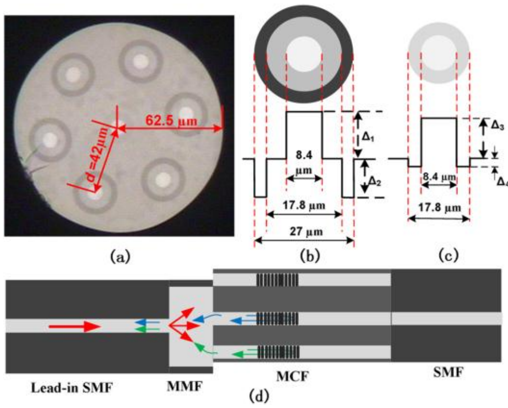


Figure 3 (a) Sectional View of Heterogeneous Seven-core Fibre (b) Peripheral Core (c) Center core (d) Sensor Structure

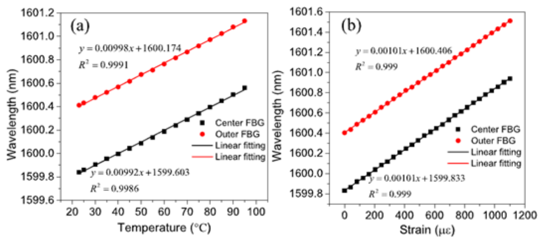


Figure 4 (a) Temperature Coefficient Measurement Results (b) Stress Coefficient Measurement Results

2.2 Multi-core Fibre High Temperature Sensor

As shown in Figure 5, that Michelson interference structure in the line is realize by tapering the multi-core fibre and the single-mode fibre and performing arc discharge at the end of the multi-core fibre to form a reflecting surface. Optical signals entering through single-mode fibre are coupled into the peripheral cores of multi-core fibre in the tapered area, and then form interference again in the tapered area by end reflection.

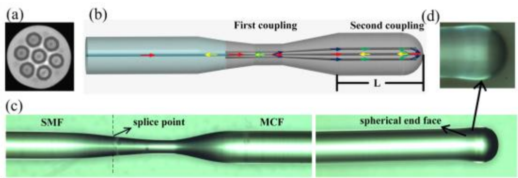


Figure 5 (a) Section of Multi-core Fibre (b) Schematic Structure of Optical Fibre (c) Photograph of Optical Fibre under Microscope (d) End Reflection Surface under Microscope

The temperature response coefficient of the Michelson Interferometer is greatly enhanced due to the SDM and multipath interference structure in the multi-core fibre, and the sensitivity of 165 pm/°C is finally achieved, which is much higher than that of the conventional Michelson Interferometer. And the high temperature measurement above 900℃ is achieved at the same time, as shown in Figure 6.

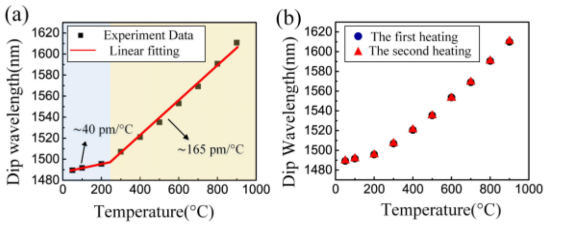


Figure 6 (a) Temperature Coefficient Measurement Results (b) Comparison of Two Measurement Results

2.3 Multi-core Fibre Multi-parameter Sensor

As shown in Figure 7 (a), that couple between the fibre cores is enhance at the taper by the arc discharge tapering of the heterogeneous multi-core fibre, and the two taper points and the multi-core fibre in the middle are configured as a Mach-Zehnder interferometer structure within the line. The heterogeneous multi-core fibre varies in the core material, the refractive indexes of the fibres have different responses to the external environment, thus the interference coefficients of each core are also different. Using our low-loss multiplexer/demultiplexer, the following coefficients are realized: the temperature coefficient and stress coefficient of the center core are 47.37 pm/℃ and 1.10 pm/μ ε respectively, and the temperature coefficient and stress coefficient of the peripheral core are 53.20 pm/℃ and 0.84 pm/μ ε respectively, as shown in Figure 7 (b) (c). Finally, it is realized that one multi-core fibre is used to measure the temperature and stress simultaneously with an error less than 5%.

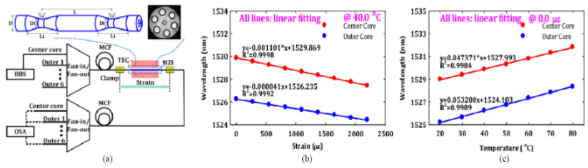


Figure 7 (a) Multi-core Fibre Multi-parameter Measurement Experimental Device (b) Stress Coefficient Measurement Results (c) Temperature Coefficient Measurement Results

2.4 Distributed Measurement Technology of 3D Shape of Multi-core Fibre

Through the research of Brillouin frequency shift of heterogeneous multi-core fibre, the R&D team found that the Brillouin frequency shift of peripheral cores changed significantly when the multi-core fibre was wound on a fibre spool of 15 cm in diameter, as shown in Figure 8 (a), while that of the center core did not change. Through further research, the Brillouin frequency shift of the peripheral core was found to be related to the fibre bending, and calibration was carried out to obtain the curvature coefficient: 2.0576±0.02132 MHz/m^{-1}. Through this technology, the measurement of distributed curvature and deformation of optical fibre is realized.

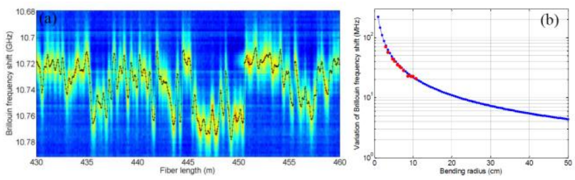


Figure 8 (a) Brillouin Gain Spectrum of Peripheral Core (b) Relationship between Bending Radius and Brillouin Frequency Shift of Peripheral Core

3 Research Progress of Distributed Bending Sensing Technology Based on Few-mode Fibre

Few-mode fibre is a kind of single-core fibres, which has a larger mode field area than common single-mode fibre, and allows a small number of fibre modes to transmit together in the fibre. By means of center-aligned fused biconical taper, the few-mode fibre is connected to the single-mode device, which ensures that only the fundamental mode in the few-mode fibre is excited. The bending Brillouin coefficient of the few-mode fibre is measured by Brillouin time domain analyzer (as shown in Figure 9). The result shows that the bending Brillouin frequency shift of the few-mode fibre is much more sensitive than that of the single-mode fibre, and the bending Brillouin frequency shift coefficient of the few-mode fibre is 11.49MHz•cm^2, as shown in Figure 10.

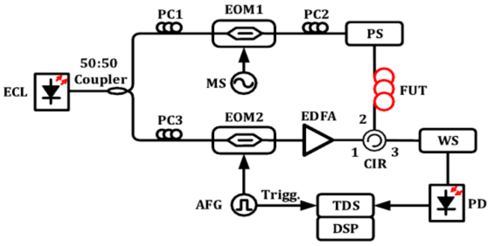


Figure 9 Distributed Curvature Measurement Device Based on Few-mode Fibre

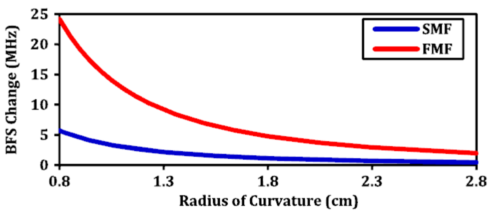
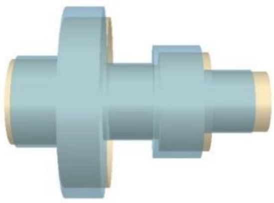


Figure 10 Response Results of Bending Brillouin Frequency Shift of Single-mode and Few-mode Fibres

Based on the results, the 3D shape measurement based on few-mode fibre is realized. A few-mode fibre was uniformly wound on a bubble model as shown in Figure 11 (a), and the bending radius of the fibre and the length of the fibre under different bending radius were obtained by Brillouin frequency shift measurement of the fibre. Finally, the 3D shape of the measured object is restored, as shown in Figure 11 (b), the blue part is the real object, and the golden part is the result restored from measurement.

(a）



(b)

Figure 11 (a) Object to Be Measured (b) Results of 3D Shape Measurement

Looking ahead, the multi-core fibre and few-mode fibre will play a more and more important and unique role in the application of bending, high temperature sensing, multi-parameter sensing, distributed sensing of 3D deformation and other technologies, and will also constantly break through the bottleneck of single or multi-mode fibre sensor or conventional optical fibre sensor in the sensing application, and widen the new dimension of specialty optical fibre in the sensing application field.

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