Effect of macro-bending on dispersion of dispersion compensating fibres

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Using direct measurement the effect of macro-bending on the dispersion in dispersion compensating fibres was investigated. It was shown that even a relatively large bend radius of ~10cm can modify the fibre dispersion in the range 1500-1600nm.

Macro-bending with radii in the range from a few to tens of centimetres always occurs when fibres are used. Any effect of macro-bending on the fibre dispersion will have a major impact on the engineering aspects of fibre implementation such as packaging, installation and characterisation conditions etc. In conventional singlemode fibres such as dispersion shifted and standard telecom fibre, the macro-bending effect on dispersion is effectively negligible. The induced bending loss is the dominant effect, i.e. with a decrease in bending radius no significant change in dispersion takes place before the induced loss makes the fibre literally unusable. The situation can be dramatically different in dispersion compensating fibres (DCFs).

Silica-germanium dispersion compensating fibres currently achieve a dispersion of ~100ps/nm/km at 1550nm [1]. The fibres have a complex refractive index profile, high 4\pi, and a small core size to maximise the waveguide dispersion. The near field distribution of the electric field therefore plays the major role in determining the dispersion properties of the fibre. Fibre bending induces radial asymmetry in the field distribution affecting the fibre dispersion properties. In this Letter, we experimentally investigate the effect of macro-bending on dispersion compensating fibres.

For dispersion measurement, an interferometric technique [2] based on the application of a supercontinuum fibre laser source was used. The setup allows accurate and detailed data on dispersion to be obtained in the entire window of transparency of silica fibres. The interferometer incorporated two fused couplers providing significant simplicity in alignment in comparison with bulk optics configurations. The couplers had close to 3dB splitting ratio in the spectral range 1.1-1.7\mu m where measurements were undertaken, and were compensated for one against another in the interferometer to maximise the contrast of the interference pattern over the entire spectral range. The test fibre was typically 60cm long. The reference path was formed by two bulk collimators with one placed on a motorised precision translation stage which provided a variable delay. A supercontinuum self-Q-switched Yb fibre laser [3] was used as a 'white-light' source to feed the interferometer. The source provided a unique spectral brightness of > 0.2mW/\mu m in the spectral range 1.1-1.75\mu m. The laser was packaged in a compact, diode pumped module of 115 \times 130 \times 15mm making it simple and convenient to use. The high brightness and broad bandwidth of the source allowed the measurements to be undertaken in the spectral domain with a high spectral resolution using a conventional spectrum analyser. By monitoring the interferometric pattern in the spectral domain, the centre of the pattern corresponds to the wavelength for which the optical paths of the interferometer are equal. Scanning the reference path, the centre wavelength was measured as a function of the delay. The group delay against the wavelength of the test fibre results are obtained directly from this measurement, and the dispersion is then calculated as

\[ D = \frac{1}{L} \frac{\partial s}{\partial \lambda} \]  

where D is the dispersion, L the length of the test fibre, c the speed of light in a vacuum, \lambda the wavelength, and \phi the delay length of the reference path of the interferometer. Fig. 1(i) shows the measured group velocity delay against wavelength for the case of unbent fibre. It can be seen that the technique allows the data to be obtained with high spectral resolution. For this curve, approximately 70 points were collected in the range 1200-1600nm with a step of 5-10nm. The dispersion curve in dispersion compensating fibres can be complicated, and detailed data over a wide spectral range are essential to obtain an accurate dispersion curve. Fig. 1(ii) shows the resulting dispersion profile. To obtain this curve, the interpolation method was used to fit to the experimental data. Two interpolation functions were used, a fifth-order Sellmeier function and a fifth-order polynomial function, depending on the shape of the curve. The fitted curve was differentiated and the quality of the fitting was tested by comparing it with direct point by point differentiation of the experimental points. For the type of curve shown in Fig. 1, polynomial interpolation was found to work better giving more accurate results at both ends of the measurement range.

![Fig. 1 Delay time and dispersion for different bending diameters](image-url)
quantified in order to establish the priority between the dispersion and loss effects under bending. It is well known that with a decrease in bending diameter the fundamental mode becomes less confined and this may result in bending loss. The bending loss is strongly dependent on the wavelength and increases exponentially with wavelength [6]. Several measurements were performed. First, the fibre was wound onto two drums with diameters of 16.5 and 28 cm, and the loss was measured as a function of wavelength using a commercial setup based on the cut-back method. The results are shown in Fig. 2(i) and (ii). The losses in the fibre are identical up to wavelengths above 1600 nm for both measurements indicating that no induced bend losses are present in the fibre for diameter of 16 cm and larger. To confirm the result, the induced bend loss was measured in the 1500–1580 nm range with a spectral resolution of 1 nm using a tunable laser. Fig. 2(ii) shows the ratio of loss measured in a 100 m piece of DCF for two diameters 13 and 32 cm. The accuracy of this measurement was ±0.05 dB, and the results are in good agreement with the first measurements.

These results prove that no noticeable losses are induced in the studied DCF in the spectral range 1500–1600 nm for a bend diameter of at least 20 cm. However, this bending is proved to change the dispersion by as much as 20% and considerably modify the dispersion slope.

In conclusion, the characteristics of dispersion compensating fibres can be modified significantly as a result of macro-bending which may occur in fibre packaging, installation etc. We have quantified and reported this variation in dispersion with bend radius for a single DCF although we have recorded similar trends in other DCFs.

Acknowledgments: F. Koch is supported by the UK EPSRC studentship.

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Electronics Letters Online No: 19990443
DOI: 10.1049/el:19990443

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References

Fibre optic load sensors with high transverse strain sensitivity based on long-period gratings in B/Ge co-doped fibre

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A novel application is reported of long-period fibre gratings produced in non-high-birefringence fibre as fibre optic load sensors based on the measurement of the transverse strain induced birefringence. A transverse strain sensitivity some 800 times higher than that previously reported for fibre Bragg gratings has been achieved.

Introduction: Long-period fibre gratings (LPFGs) have been demonstrated as useful fibre optic devices for a number of applications including band-rejection [1], gain-flattening [2], temperature, strain and refractive index sensing [3, 4] and sensor demodulation [5]. Recently, more complex LPFG structures, such as chirped [6], cascaded [7] and phase-shifted [8] structures, have been proposed and studied for further application possibilities. In this Letter, we report, for the first time to our knowledge, a novel application of LPFGs fabricated in non-high-birefringence fibre as fibre optic load sensors based on the measurement of the transverse strain introduced birefringence. We have found that the transverse strain sensitivity achieved by the LPFG devices is ~800 times higher than that achieved using short-period gratings, e.g., fibre Bragg gratings (FBGs) previously reported [9]. The extremely high transverse strain sensitivity, combined with their ability to provide longitudinal strain and temperature sensing, suggests that LPFG devices could be used for simultaneous multi-axis strain and temperature sensing.

Experiment and results: The LPFGs used in the transverse loading experiment were fabricated using an amplitude mask of 490 μm period in B/Ge co-doped fibre without hydrogenation. Fig. 1b shows the typical transmission profile of an LPFG before being loaded, showing five broad resonant loss peaks originating from the coupling between the core and the cladding modes LP02, LP03, LP04, LP05 and LP06. The transverse loading experiment was implemented by first laying the LPFG fibre and a dummy fibre of the same type between two flat surfaces, and then gradually increasing the load on the top (Fig. 1a). The transmission spectrum was measured using a system incorporating a broadband LED light source, a fibre polarisation splitter and a polarisation controller, and an optical spectrum analyser. For each value of applied load,