FABRICATION AND CHARACTERISATION OF CIRCULARLY BIREFRINGENT HELICAL FIBRES

Indexing term: Optical fibres

A technique for fabricating helical-core circularly birefringent fibres is reported. Extremely high levels of circular birefringence are achieved ($B = 2{\cdot}1 \times 10^{-4}$ at 633 nm). Because of its unique structure, this fibre remains single-mode up to V values of 25.

Introduction: Single-mode optical fibres capable of maintaining stable polarisation states are required in many important fibre sensors and devices. Polarisation-maintaining fibres fall generally into three main types: the linearly birefringent fibre of which the bow-tie[1] fibre is perhaps the best known, the elliptically birefringent fibre,[2] e.g. a spun bow-tie fibre, and the circularly birefringent fibre.[3,4]

Helical-core fibres exhibit high levels of circular birefringence, and because optical rotation is achieved in the fibre by geometric effects they are not highly temperature-sensitive, unlike the other two types of birefringent fibre. This makes them suitable for Faraday rotation sensing as in current monitors.

A novel feature of the helical fibre structure is the large core diameter, which can be an order of magnitude greater than that of conventional single-mode fibres, while still providing single-mode operation. This phenomenon is due to the small radius of curvature of the helical core, which induces severe bend loss for higher-order modes and allows single-mode operation at V values of up to 25. With this large core, high launching efficiency and power transmission levels can be achieved in spite of the skew nature of the core.

Theory of operation: It has been observed[5] that when light is constrained to follow a helical path it experiences an optical rotation. This rotation length can be expressed as[4]

$$L_r = \frac{SP}{S-P} \simeq \frac{P^3}{2\pi^2 Q^2} \quad P \gg Q \qquad (1)$$

where P is the helical pitch length, S is the arc length for one pitch and Q is the offset of the core from the fibre axis. A helical-core fibre is shown schematically in Fig. 1. From eqn. 1 it can be seen that to maximise the circular birefringence, i.e. minimise rotation length, in the helical fibre a large offset and a small pitch length is required.

Fabrication: The helical fibre is drawn from a spinning preform in which the core has been offset from the axis. Fibres have been drawn from preforms with both solid and hollow structures.

Solid preform construction: An off-axis longitudinal hole is drilled in a large silica rod using an ultrasonic drilling machine. A guiding rod of higher index is then inserted into the hole. This rod can either be a high-index doped silica rod, or for lower loss a standard MCVD preform can be used. In both cases high-index cores are required to minimise bend losses. Large core offsets are achieved by drilling the hole as close to the substrate edge as possible.

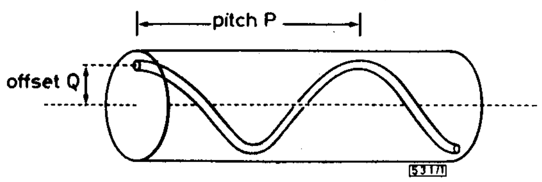

Fig. 1 *Schematic diagram of helical fibre*

Hollow preform construction: The hollow construction is achieved by attaching a doped silica-core rod or a redrawn MCVD preform to the inside wall of a silica tube. The guiding rod is attached to the inside wall to give mechanical protection to the core during fibre drawing and subsequent handling.

Fibre fabrication: The two types of preform are drawn into helical fibres using a modified drawing technique. The preforms were mounted in a chuck attached to a spinning motor, capable of rotating at 2000 rev/min. During the drawing process the preforms were spun to impart a twist to the fibre. Figs. 2*a* and *b* show typical solid and hollow helical fibre cross-sections using an MCVD preform as the guiding rod. Fig. 2*c* shows clearly the helical path of the core. By careful control of the drawing conditions it is possible to anneal out any stress-induced bend birefringence and still maintain good circular-core geometry.

Fibre characterisation: Table 1 gives results for both solid and hollow fibres. The solid preform was constructed by redrawing an MCVD preform to 3 mm and inserting it into a 27 mm OD predrilled, silica substrate. The hollow preform used a 3 mm MCVD preform attached to the inside of 28 mm OD, 25 mm ID silica tube. Launching into the fibre was achieved using two techniques. First, during the drawing stage a small section of fibre was left unspun. Light was then subsequently launched into this unspun section of fibre. Alternatively the fibre end was tapered down to give a section which was effectively unspun and resembled a conventional single-mode fibre with an offset core.

The optical rotation length L_r was then determined by a cutback method. In this, plane-polarised light at 633 nm was launched into the fibre using a strain-free lens, and an analyser was crossed with the output to give a null. Various lengths of fibre were consecutively removed and the analyser rotated to give a null. The optical rotation length corresponds to a 2π rotation of the analyser. During repeated cutbacks the extinction ratio remained excellent, showing the fibre to have a very low linearly birefringent component.

Discussion: Table 1 shows good agreement between measured and predicted values for optical rotation length. Discrepancies are mainly due to errors in pitch length measurement. An optical rotation length as short as 6 mm has been obtained giving a beat length (i.e. $\frac{1}{2}$ rotation length) of 3 mm and a circular birefringence $B = 2{\cdot}11 \times 10^{-4}$ at 633 nm.

The fibres were locally heated to approximately 300°C with no change in the output state of polarisation. The helical fibres were still single-mode with a V value of 25. This value was determined by comparing single-mode fibre diameters from spun and unspun fibres.

Table 1

Fibre type	NA	Core offset	Pitch	Fibre dia.	Optical rotation length	rotation length
		μm	mm	μm	mm	mm
Hollow	0·22	75	1·8	200	45	53
	0·22	194	2	450	10	10·8
Solid	0·3	170	1·6	450	9·6	7·2
	0·2	330	4	780	34	30
	0·2	260	2·7	625	16	14·8
		340	2	800	6	3·6

* Obtained from eqn. 1

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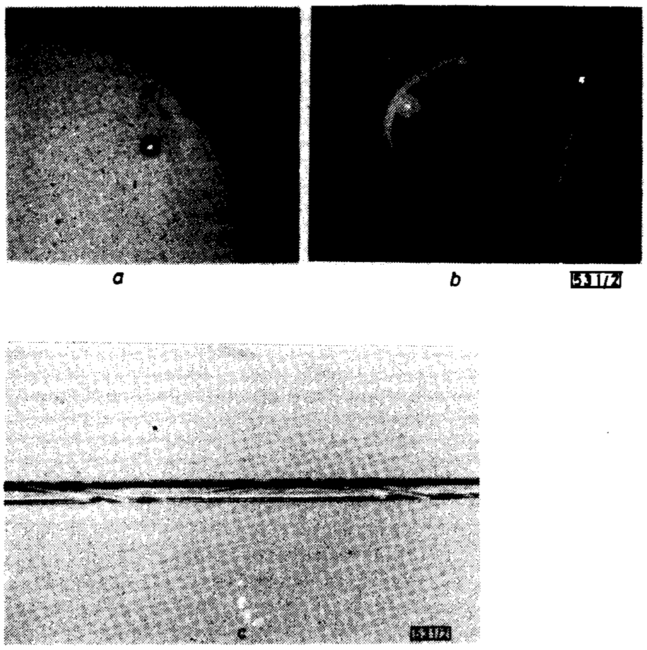

Fig. 2

a Cross-section of solid helical fibre
b Cross-section of hollow helical fibre
c Transverse view of hollow helical fibre

Conclusions: Two techniques for fabricating circularly birefringent helical fibres have been demonstrated. The fibres are simple to fabricate using a small modification to standard drawing technology. In spite of the small effective bend radius of the core, the fundamental mode is well guided, owing to the fibre having a high NA and by operating the fibre with a very large V value. With the large fibre core diameter, high launching efficiencies and high power transmission levels are possible. Circular birefringence in the fibre is due to purely geometric effects and results in a helical fibre with low temperature sensitivity. High levels of circular birefringence have been achieved ($B = 2{\cdot}11 \times 10^{-4}$ at 633 nm) with beat lengths as short as 3 mm. These values of circular birefringence are similar to those quoted for the best linearly birefringent fibres and suggest that the helical-core circularly birefringent fibre will have excellent polarisation-holding properties.

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