CIRCULARLY BIREFRINGENT SINGLE-MODE OPTICAL FIBRES

Indexing terms: Optical fibres, Polarisation

The rotation of polarised light which occurs in a twisted anisotropic medium is exploited to produce very high circular birefringence in single-mode optical fibres. Beat lengths of less than 5 mm have already been achieved in some preliminary experiments.

Introduction: In a circularly symmetric single-mode fibre the linearly polarised propagating field can be resolved into two orthogonal x and y linearly polarised components or into two orthogonal left and right (L and R) circularly polarised components, all having the same propagation constants.

Linear birefringence is introduced by breaking the degeneracy between the x and y polarised propagation constants ($\beta_x \neq \beta_y$), and has been achieved with an elliptical core structure[1] or with an anisotropic stress across the core.[2,3]

Circular birefringence (or optical activity) is introduced by breaking the degeneracy between the L and R circularly polarised propagation constants ($\beta_L \neq \beta_R$), and has been achieved to a certain extent in fibres by making the fibre follow a helical path[4,5] or by using torsional stress.[6]

In this letter we demonstrate a new method of achieving very high levels of circular birefringence in single-mode fibres. The method is based on the rotation of polarised light which can be obtained in twisted anisotropic media when the anisotropy is large.[7] We introduce an intuitive approach here—a more rigorous analysis is presented elsewhere.† Such fibres have been fabricated and we have obtained beat lengths down to 4·3 mm in some preliminary experiments. This is the highest level of circular birefringence ever reported in a single-mode optical fibre.

Core structures for circular birefringence: If a twist is to have any influence on the propagating field it is necessary to introduce some azimuthal inhomogeneity into the core. For our purposes we require some very large inhomogeneities in the form of single-lobe or multiple-lobe core structures, a few variations of which are shown in Fig. 1.

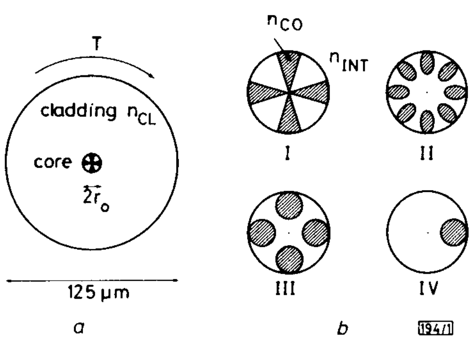

Fig. 1

a Typical fibre cross-section defining fibre parameters
b Possible azimuthally inhomogeneous core structures

The inhomogeneity must not introduce any linear birefringence, namely:

(i) if the lobes are coupled then the overall core structure must not introduce any linear birefringence, e.g. cases I, II and III of Fig. 1*b*

(ii) if the lobes are uncoupled then each lobe must itself have no linear birefringence, e.g. case II of Fig. 1*b*

(iii) since the lobes of (ii) are uncoupled then a single lobe having no linear birefringence will also suffice, e.g. case IV of Fig. 1*b*.

To achieve high circular birefringence the lobe refractive index of the lobe should be much greater than that of the intermediate core region (i.e. $n_{CO} > n_{INT}$) and that of the cladding (i.e. $n_{CO} > n_{CL}$). Performance is improved by lowering the refractive index of the intermediate core region relative to the cladding ($n_{INT} < n_{CL}$).

Our analysis† shows that when these structures are twisted along the axis of the fibre then under special circumstances the polarisation can be made to rotate at a rate equal to the twist rate τ.

The maximum allowable twist rate for full twisting efficiency is governed by the index difference $\Delta n = n_{CO} - n_{INT}$ and the core radius r_0 (i.e. outer radius of the lobes). By twisting a given fibre at faster rates the field is no longer strongly guided and the polarisation tends to slip. Higher optical rotation rates require a higher lobe refractive index and a smaller lobe core radius.

Fabrication technique: Suitable preforms can be fabricated using the gas phase etching technique[2] or more simply by using a rod-in-tube technique with a number of rods where the rods can be standard MCVD preforms. The resulting preform is spun and drawn using standard drawing procedures.

Preliminary results: To demonstrate the technique the simplest structure was investigated, e.g. case IV of Fig. 1*b*. A single MCVD preform was used to provide the lobe. The fibre parameters were $\Delta n = 0{\cdot}01$, core radius $r_0 = 10\ \mu m$, $n_{CL} = n_{INT}$, the lobe was such that an unspun length of the fibre was single-moded at $\lambda = 0{\cdot}633\ \mu m$ and the overall fibre diameter was 110 μm. The fibre was spun at various rates in the range of 250–50 turn/m.

To analyse the fibre an He-He laser was used to illuminate a 2 m length of fibre. The output was found to be plane-polarised for a plane-polarised input and was circularly polarised for a circularly polarised input.

The beat length was measured under plane-polarised illumination by two methods. First, the rotation of the polarisation at the fibre output was monitored as the fibre was cut back, the length removed for a 180° rotation corresponding to a beat length. Secondly, the variation of Rayleigh scatter transverse to the fibre was observed giving a direct measurement of beat length. The two measurements were in excellent agreement. Table 1 shows the beat lengths obtained for various twist rates.

Table 1 MEASURED TWIST RATES AND BEAT LENGTHS ON OUR SAMPLE FIBRE

Twist rate	Optical rotation rate	Beat length
T/m	T/m	mm
50	50	10
83	83	6
100	100	5
116	116	4·3
160	14	35
250	10	50

Table 1 clearly shows that the optical rotation for this fibre closely follows the twist rate for rates less than or equal to 116 turn/m. For faster twist rates the optical rotation rate tends to slip well behind. In fact, the resulting optical rotation rate never exceeds the maximum of 116 turn/m irrespective of the twist rate.

Conclusion: The technique of producing a strongly circularly birefringent fibre by twisting an azimuthally inhomogeneous core has been demonstrated with the simplest structure possible. A beat length of 4·3 mm at $\lambda = 0{\cdot}633\ \mu m$ has been achieved in a single-lobe fibre with a core radius of 10 μm and an overall fibre diameter of 110 μm. This fibre should find new and exciting applications in the areas of sensors, devices and optical communications. We have only reported preliminary results here. We are confident that with improved designs,† i.e. increasing the Δn value and reducing the lobe core radius, we will shortly achieve substantially shorter beat lengths with this technique.

† FUJII, Y., and HUSSEY, C. D.: 'Design considerations for circularly form-birefringent optical fibres', unpublished

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