FABRICATION OF SINGLE-MODE FIBRES EXHIBITING EXTREMELY LOW POLARISATION BIREFRINGENCE

Indexing terms: Mechanical birefringence, Optical fibres

An investigation of the relative effects of core ellipticity and stress-induced birefringence on fibre polarisation properties is described. It is found that a reduction in core stress levels is necessary to obtain low-birefringence fibres. A fibre having a retardation of only 2·6°/m is reported.

Introduction: There is currently a great deal of interest in the development of single-mode fibres capable of transmitting linearly polarised light.[1–3] Conventional monomode fibres exhibit linear birefringence such that the input state of polarisation is severely modified within a few cm.[1] Furthermore, the output state is found to be affected by temperature and kinking of the fibre. The indeterminacy of the output polarisation is a considerable disadvantage in fibre applications that rely on the measurement of small optical phase shifts by means of an interference effect,[4,5] since the latter requires collinearity of the polarisation of the interfering beams. The presence of intrinsic fibre birefringence also causes a loss of sensitivity and stability in the Faraday-effect current transducer.[6]

We report here a systematic attempt to reduce the birefringence to an insignificant level. By careful attention to fabrication techniques, fibres with the required degree of core circularity[7] and low residual stress levels are possible, resulting in fibres having remarkably low birefringence. The relative effects of core ellipticity and stress are illustrated by means of three fibres, exhibiting progressively improved polarisation characteristics. The approach is similar to that taken in Reference 8, but contrasts with that of Reference 3 where a high birefringence was sought.

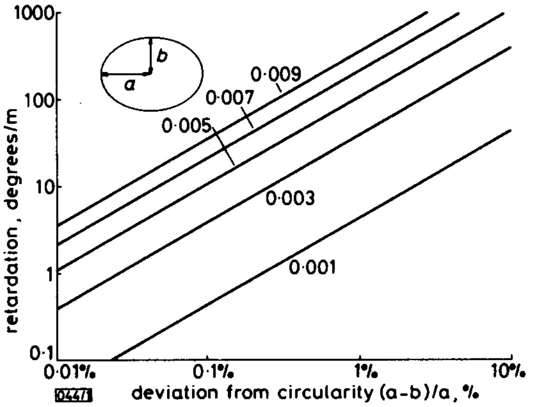

Fig. 1 *Retardation as a function of core circularity in a fibre having $V = 2{\cdot}4$ at $0{\cdot}633\ \mu m$*

Curves are for the values of relative index difference Δ shown

The fabrication of low-birefringence fibres requires a reduction in both core stress levels and ellipticity. Fig. 1 shows the phase retardation $\delta\beta$ produced by a given deviation from core circularity for various values of relative core/cladding index difference Δ, calculated using the theory of Reference 7. It may be seen that the tolerance on circularity can be relaxed by choosing a small index difference (and, by inference, a large core).

For the current transducer a retardation of ≈ 3°/m is required, corresponding to a phase difference of 2π between fast and slow modes in a length of 120 m (the 'periodic length'). From the curves this corresponds to a deviation from circularity of no greater than 0·1% for a fibre having $\Delta = 3 \times 10^{-3}$, a geometrical perfection which has hitherto been difficult to achieve. Note, however, that previous analyses would indicate that a considerably higher circularity is required.

Results: A series of fibres was fabricated to investigate the relative effects of core circularity and residual stress on birefringence. The characteristics of three of these are given in Table 1. All fibres were coated with silicone resin having a thickness of approximately 50 μm.

Table 1

Fibre	VD214	SV1	GSB2
Core composition	SiO_2	SiO_2	GeO_2/SiO_2
Core diameter, μm	8·5	9·0	4·0
Cladding composition	B_2O_3/SiO_2	Vycor	B_2O_3/SiO_2
Cladding diameter, μm	36	—	16·5
Substrate tube	silica	Vycor	silica
Overall fibre diameter, μm	140	140	85
Relative index difference, Δ	$7{\cdot}6 \times 10^{-4}$	$7{\cdot}4 \times 10^{-4}$	$3{\cdot}4 \times 10^{-3}$
V-value at 633 nm	2·4	2·5	2·4

Fibre VD214: The fibre was made by chemical-vapour deposition of B_2O_3-doped SiO_2 within a high-quality silica tube (Heralux WG), followed by deposition of pure silica to form the core. A low index difference was chosen to relax the requirement on core circularity. The deviation from circularity was determined to be less than 1% by etching the fibre end in hydrofluoric acid and examining it under a high-power optical microscope. From Fig. 1, this level of ellipticity is expected to produce a linear retardation of less than 2·4°/m.

The birefringence measurements on a straight section of the fibre are shown in Fig. 3. The specific retardance was found to be 126°/m, a figure considerably in excess of that calculated. It would seem, therefore, that residual stress birefringence in the fibre caused by the thermal-expansion mismatch between core and cladding has a major effect on the retardation, a conclusion similar to that drawn in Reference 3.

Fibre SV1: Vycor glass has an expansion coefficient close to that of silica, but has a somewhat lower refractive index. These characteristics may be utilised to produce a fibre with a low residual stress level. Using a silica rod and a Vycor tube, a fibre was fabricated having the characteristics shown in the Table. Again the ellipticity was better than 1%, indicating an expected retardance of 2·2°/m (Fig. 1). From the experimentally determined retardation shown in Fig. 3, it may be inferred that the reduced stress level has resulted in an improved value of 66°/m. However, an order of magnitude discrepancy still exists between the experimental value and that calculated on the basis of core ellipticity.

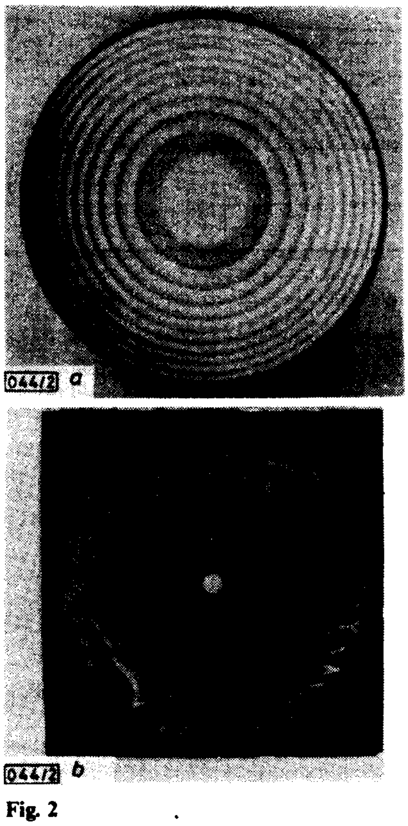

Fig. 2

a Cross-section of deposited region of GSB2 preform. Rings are the B_2O_3-doped layers and the central bright region the GeO_2-doped core
b Fibre produced from preform

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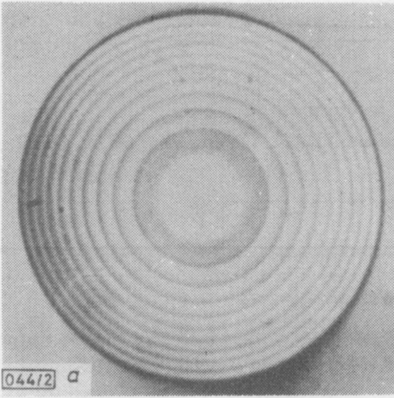

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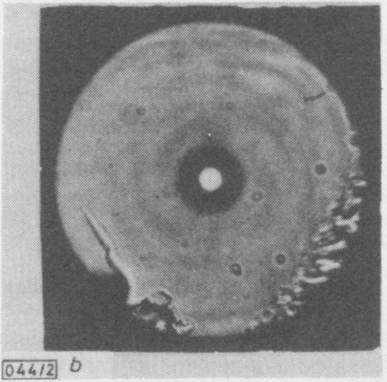

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Fibre GSB2: Stress-induced birefringence in a fibre is caused by an imbalance in the transverse stress components along the two axes of an elliptical core or cladding. The imbalance may be diminished and a reduction in overall core stress levels achieved by choosing the thermal expansion coefficients of the deposited core and cladding to be equal. In this case, core and cladding are indistinguishable from a mechanical point of view and have equal stress levels. Furthermore, the tensile forces are now distributed over the total area of deposited glass, resulting in a reduction in the core stress level.

A B_2O_3/SiO_2 cladding and a GeO_2/SiO_2 core having matched expansion coefficients were deposited within a silica tube to produce a preform, the cross-section of which is shown in Fig. 2*a*. The index difference Δ was chosen to be $3{\cdot}4 \times 10^{-3}$, a value higher than in the previous fibres, to allow realistic doping levels. Fig. 1 indicates that for this Δ an ellipticity of better than 0·06% is necessary to achieve a retardance of 3°/m.

Despite this, measurement of the birefringence properties of the fibre (cross-section in Fig. 2*b*) drawn from the preform exhibited remarkably low values of retardance, a value of only 2·6°/m being found (a periodic length of 140 m) (Fig. 3).

Conclusions: Single-mode fibres have been produced with the calculated degree of circularity required for low retardation. Moreover, with careful control of residual stress levels, fibres with extremely low birefringence are attainable. The retardation achieved (2·6°/m) is the lowest yet reported and is 3 orders of magnitude lower than in typical fibres. The matched expansion coefficients in core and cladding would also appear to reduce the sensitivity of the birefringence to temperature variations, thus suiting the fibre ideally to current measuring instrumentation. One of the fibres is presently being used in a prototype current transducer, undergoing tests on the effect of pressure, vibration and temperature. Initial results are favourable and indicate that the fibre characteristics make such a device a practical reality.

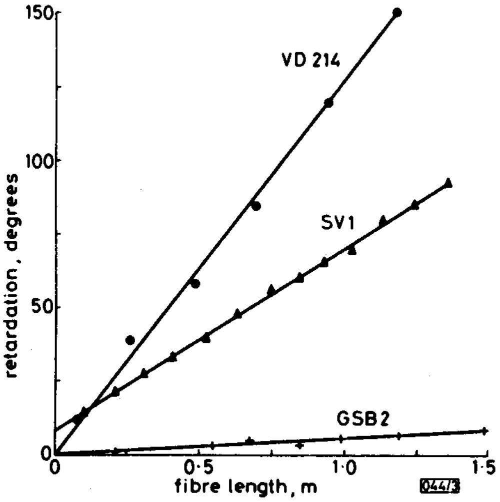

Fig. 3 *Phase retardation of fibres shown*

Specific retardance values are VD214: 126°/m, SV1: 66°/m, GSB2: 2·6°/m

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S. R. NORMAN
D. N. PAYNE
M. J. ADAMS

Department of Electronics
University of Southampton
Southampton SO9 5NH, England

A. M. SMITH

Central Electricity Research Laboratories
Kelvin Avenue
Leatherhead KT22 7SE, England

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