FABRICATION OF A STRESS-GUIDING OPTICAL FIBRE

Indexing terms: Optical fibres, Stress guidance, Fabrication

The principle of stress guidance in optical fibres is described. An optimum-stress-guidance structure has been designed and fabricated using gas-phase etching. The fibre is the first to have truly single-polarisation operation for all V-values.

Introduction: Recently it has been shown that single-mode fibres using the photoelastic effect to induce birefringence[1] have bending/microbending loss edges separated in wavelength for the two orthogonally polarised modes[2] and can therefore be operated with one polarised mode suppressed over a wavelength region of about 60 nm. Such fibres are currently finding widespread application for uses as polarisation-maintaining fibres in optical-fibre sensors. However, single-polarisation operation of a multimode fibre, or equivalently, single-polarisation operation of a fibre over all wavelengths, has not been reported to date.

Recently, an alternative approach to the design of truly single-polarisation fibres has been proposed using the photoelastically induced stress guidance provided by a highly doped and index-matched elliptical core.[3] In this letter we report on the realisation of a similar fibre which uses the optimal 'bow-tie' stress-producing geometry.[4] The design and fabrication of the fibres is described and results are presented for the first single-core and double-core stress-guided fibres which can be operated either as single-mode or as multimode-fibre polarisers.

Stress guidance: The principle of stress guidance is to make a photoelastically induced waveguiding structure, which will be 'seen' by light polarised in one direction only. This principle differs from that of high-birefringence fibre design because high-birefringence fibres support linearly polarised modes in two orthogonal directions.

Consider the bow-tie fibre cross-section shown in Fig. 1*a*. Here, the waveguiding structure consists of a germania doped core and silica inner cladding of refractive indices n_1 and n_2 respectively. The stress-producing sectors modify the refractive indices of the core and inner cladding by the photoelastic effect, such that for x-polarised light the core has index $n_1 + B/2$ and the cladding $n_2 + B/2$. For y-polarised light the indices are $n_1 - B/2$ and $n_2 - B/2$, where B is the modal birefringence. Note that both polarisations see the same index difference $n_1 - n_2$ between their respective cores and claddings.

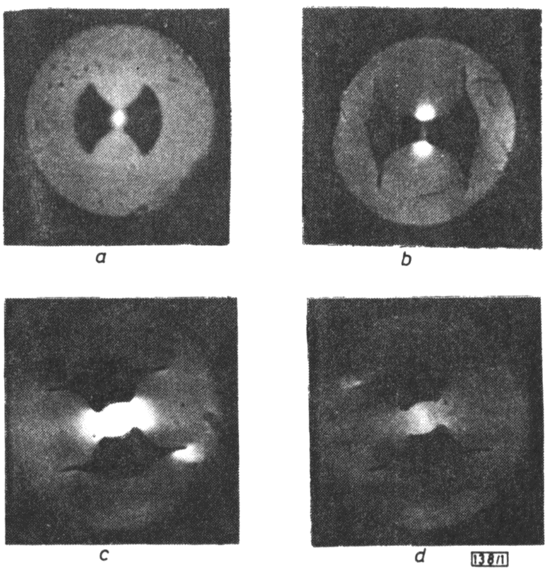

Fig. 1

a High-birefringence bow-tie fibre with doped core
b Stress-guidance fibre with pure silica core
c, *d* Stress-guidance fibre with phosphorus compensated core—x-polarised light, y-polarised light, respectively

In a stress-guidance fibre the core region is undoped ($n_1 = n_2$) and the index difference seen by the two polarisations becomes approximately $B/2$ and $-B/2$. Thus by inducing sufficient birefringence it is possible to produce a positive index difference for one polarisation, and a negative one (an antiguide) for the other. The optimum structure which produces the best stress-guidance is clearly the bow-tie configuration, since this gives maximum stress anisotropy and hence B for a given expansion coefficient mismatch. The design of the dimensions of the bow-tie sections follows from Reference 4.

Figs. 2*a* and *b* show the theoretical photoelastically induced refractive-index profiles seen by x- and y-polarised light. These profiles were obtained using the relationships

$$n_x = -C_1\sigma_x - C_2(\sigma_y + \sigma_z)$$

$$n_y = -C_1\sigma_y - C_2(\sigma_z + \sigma_x)$$

where the stresses σ_x, σ_y and σ_z were obtained using finite elements,[5] and C_1 and C_2 are the stress-optic coefficients. From Fig. 2 we see that the core is raised for x-polarised light, but depressed for y-polarised light, as predicted. Thus only modes polarised in the x-direction are guided.

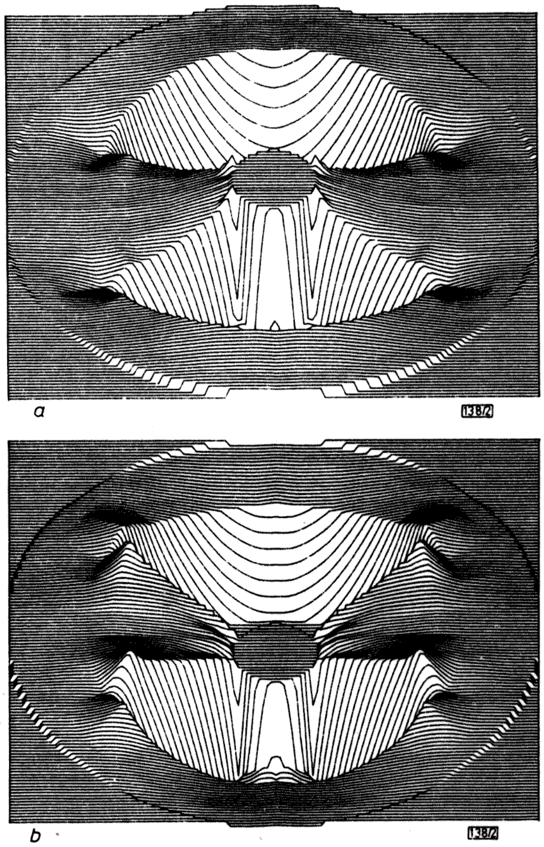

Fig. 2 *Theoretical 3-D photoelastic refractive-index profiles*

a x-polarised light
b y-polarised light

The principle of stress guidance can be extended by very slightly doping the core to raise the index difference to B for light polarised in the x-direction whilst ensuring that light polarised in the y-direction sees $n_1 \simeq n_2$, and thus is not guided. Note that the existence of the depressed bow-tie regions does not produce a guiding structure for y-polarised light, since the index of the core is at or below that of the silica inner cladding and substrate. The equivalent NA of such a stress guide is then $\sqrt{(2n_2 B)}$ where $n_2 \simeq 1{\cdot}46$.

Fabrication: The two fibres shown in Figs. 1*b*–*d* were made using gas phase etching.[1] The first, Fig. 1*b*, has a nominally pure silica core which in fact was found to be slightly depressed by boron diffusing in from the borosilicate stress-producing regions. However, the pure silica stress guides are clearly visible on either side of the core. The second fibre, Figs. 1*c* and *d*, has the core very lightly doped with phosphorus to balance the antiguide seen by y-polarised light and thus increase the index difference experienced by the x-polarisation.

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The doping also counteracts the boron diffusion.

The operation of the stress-guide is illustrated in the micrographs shown in Figs. 1*c* and *d*, where polarised white light was respectively aligned and crossed to the guide axes. Polarising action in this 20 mm length of multimode stress guide is clearly visible.

Results: Circularly polarised light (633 nm) was launced into a 1 m length of the phosphorus-doped fibre shown in Figs. 1*c* and *d* and an analyser used to investigate its polarisation properties. The fibre was found to be single mode when pulled to a diameter of 80 μm or less and the far field was linearly polarised. To eliminate the possibility that the fibre was supporting two orthogonally polarised modes which were interfering at the output to produce linearly polarised light, the fibre was cut back several times and also locally heated. These tests produced no change in the output state of polarisation. Moreover, when white light was launched into a 0·5 m length of 600 μm diameter fibre ($V = 18$) the output was again linearly polarised. These tests conclusively verify the existence of the stress guide seen by x-polarised light.

The NA obtained from a far field measurement on a 70 μm diameter was estimated to be 0·027 which increased to 0·036 when the stress anisotropy in the core was increased by thermal annealing.[6] Similar measurements on the pure-silica stress-guiding fibre (Fig. 1*b*) showed an increase in the NA for each core from about 0·016 to 0·023.

Conclusions: The first truly single-polarisation fibre has been designed and fabricated using a pure stress-guiding structure. The fibre has an NA of 0·036 and transmitted linearly polarised light for all V-values.

To obtain a feel for how important these fibres could become in future applications it is necessary to estimate the equivalent NA that has been obtained with current stress fabrication. The highest level reported[1] to date is 0·059 (633 nm); this could be further enhanced to 0·083 by thermal annealing. With these values of NA the stress-guiding fibre could clearly be used for a number of applications involving multimode polarisers and single-mode polarisers operating over a wide range of wavelengths.

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