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FABRICATION AND DEVELOPMENT OF POLARISATION-MAINTAINING FIBRES USING GAS PHASE ETCHING

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INTRODUCTION

Polarisation-maintaining fibres are of considerable interest in the field of optical fibre sensors because of their ability to transmit either of the two orthogonal linearly polarised modes over long distances - an extinction ratio of 20dB in 5km of PANDA fibre has been reported (Hosaka et al (1)). The fibres owe their polarisation holding performance to the high levels of birefringence designed into the structure. Although the form birefringence of an elliptical core can be used (Dyott et al (2)), the fibres are usually made birefringent by doping the silica on either side of the core with materials having different expansion coefficients. The resulting fibre has a birefringence proportional to the anisotropic stress across the core, whose magnitude depends upon the expansion coefficient mismatch and fibre geometry.

In this paper, the optimum structure for a polarisation-maintaining fibre is first designed and then a process to make it is described together with typical performance figures. Finally, two techniques are described to enhance the already high levels of birefringence obtainable, and experimental results are given which show how short lengths of fibre can be used as a high extinction polariser, while long lengths of fibre can be used for the transmission of linearly polarised light aligned to one of the axes only - the other linearly polarised mode being suppressed.

DESIGN

There are four practical constraints which must be met by the design seeking to optimise the birefringence. (i) The fibre must be low loss, which dictates the use of a circular core with a low loss inner cladding; (ii) The outside of the fibre must be in compression to prevent cracks propagating - i.e. the substrate must be pure silica; (iii) maximum birefringence must be obtained from any expansion mismatch achieved (which in practice is the limiting factor) and (iv) the geometry must be capable of being fabricated. The fibre is then designed using the following analytic formula (Varnham et al (3)), which relates the modal birefringence B to the expansion coefficient profile $\alpha(r,\theta)$ in a structure having mirror symmetry about $\theta = 0^{\circ}$:

$$B = \frac{1}{\pi}\,\frac{CET}{1-\nu}\int_0^1\int_0^{2\pi}\alpha(r,\theta)\,\cos 2\theta\,(r^{-1}-3r^3)\,d\theta\,dr \qquad (1)$$

where C is the stress optic coefficient, T is the temperature difference between the glass fictive temperature and room temperature, E is Young's modulus and ν is Poisson's ratio. It is assumed that E, T, ν are uniform throughout the fibre cross section, which has a normalised outer radius $r = 1$. Measuring B with respect to $\alpha(r,\theta)$ is achieved by inspection by making:

$$\begin{aligned}\alpha(r,\theta) &= \alpha_1 \quad \text{when} \quad \cos 2\theta(r^{-1}-3r^3) > 0\\ \alpha(r,\theta) &= \alpha_2 \quad \text{when} \quad \cos 2\theta(r^{-1}-3r^3) < 0\end{aligned} \qquad (2)$$

where α_1 and α_2 are the maximum and minimum expansion coefficients that can be achieved. The resulting structure shown in Figure 1(a) does not satisfy conditions (i), (ii) and (iv) above. The structure is then redesigned as shown in Figure 1(b) resulting in the optimal Bow-Tie configuration; a and b are the outer and inner radii of the bow-ties.

Figure 2 shows how the beat length $L_p = \lambda/B$ varies with $(a-b)/(a+b)$ as b is held constant. The curves have been normalised to a typical Bow-Tie fibre having $L_p = 1.2$mm when $a = 0.6$ and $b = 0.1$. It is clear from Figure 2 that b should be as small as possible while $a < 0.76$. Assuming a 125μm fibre diameter and using the design criterion that the low loss inner cladding should have the same thickness as the core radius, the minimum acceptable value of $b = 0.1$.

FABRICATION

Method

The fabrication of Bow-Tie preforms is achieved using MCVD. Low loss flourophosphorous cladding layers, index matched to silica are deposited, followed by layers of highly doped borosilicate (typically 20 $^{m}/o$ in the gas phase) Figure 3(a). The borosilicate layers are selectively etched using a fluorine liberating gas such as sulphur hexafluoride Figure 3(b). After completion of the etching process, further cladding layers and a germania core are deposited, Figure 3(c), and the tube collapsed under pressure to form a solid preform. The resulting fibre shown in Figure 3(d) has the (depressed) bow-ties and low loss core/cladding structure of the optimum geometry (3) Figure 1(b).

Results

Gas phase etching is a single step process which minimises the risk of the preform shattering. Moreover the process is controllable and routinely produces near optimal geometries, thus achieving maximum birefringence from the high dopant concentrations used. The advantages of the method is best illustrated by the best beat length result of birefringence yet reported. Typical performance figures are beat lengths

<1.3mm at 633nm with losses as low as 0.73dB/km at 1.1μm and 1.2dB/km at 1.3μm and 1.55μm. These levels of performance compare favourably with the PANDA fibre and the non-optimal elliptical jacket Hitachi fibre (Katsuyama et al (5)).

DEVELOPMENT

Enhancement of Birefringence

Jacketing Once a Bow-Tie fibre has been made, the ratio of $(a-b)/(a+b)$ is fixed. However, reference to Figure 2 shows that a reduction in beat length can be achieved by sleeving the preform, which leads to a smaller normalised value of b. For example, the effect of sleeving the fibre denoted by point A in Figure 2 can be seen by moving vertically downwards on the line AB. A 50% reduction in beat length can be achieved in this example. The above principle has been verified in a simple experiment where the beat length of a Bow-Tie fibre was monitored as the substrate was successively removed by acid etching (3).

Annealing Thermal cycling experiments have shown that annealing of Bow-Tie fibres at about 550°C can result in 50% reductions in beat length. The effect has been exploited by the on-line annealing of the (uncoated) fibre during the draw (Ourmazd et al (6)) where the beat length was reduced by up to 40%.

Single Polarisation Performance

The polarisation-maintaining property of high birefringence fibres relies on exciting only one of the two orthogonal linearly polarised modes in the hope that no coupling occurs to the other mode. However, Snyder and Ruhl (7) have shown that the condition for the suppression of the mode polarised in the y direction is that its effective index should lie below the cladding index of the x polarised mode. In practice however, the bow ties give rise to the commonly observed long wavelength microbending edge in fibres having a depressed cladding, which, because of the stress birefringence, affects both polarised modes at different V values.

Figure 4 shows the attenuation in dB/km as a function of wavelength for the x and y polarised modes of a Bow-Tie fibre. It can be seen from the curves that a wavelength region exists where the guided x mode loss is less than 5dB/km while the suppressed y mode has losses as large as 55dB/km (Varnham et al (8)). The fibre would therefore be an ideal candidate for the transmission of polarised light over long lengths e.g. in gyro coils.

The solid and dashed lines in Figure 5 show the extinction ratio in dB/km as a function of wavelength in 0.5m of the same Bow-Tie fibre before and after thermal annealing. The high extinction ratio of 50dB/km at 920nm makes the fibre suitable for use in short lengths as a discrete fibre polariser in fibre sensors, having an insertion loss <0.5dB/ m for the guided mode (8). The annealing enhances the polarising performance of the fibre because it results in a greater separation between the wavelengths at which leakage occurs, thus increasing the differential modal attenuation (8).

CONCLUSIONS

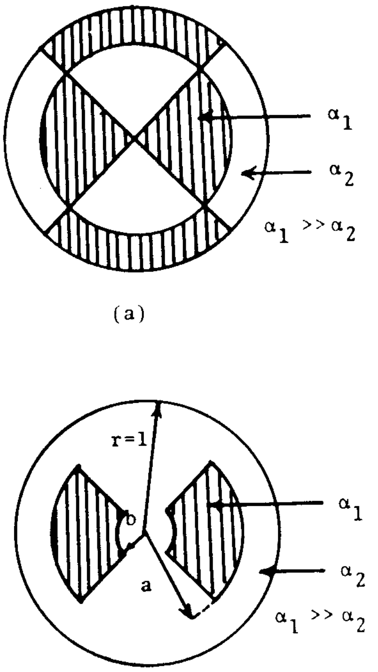
The optimal bow-tie configuration for polarisation-maintaining fibres has been designed. The bow-tie sections should have a normalised inner radius $b \simeq 0.1$ and an outer normalised radius $a \simeq 0.76$. It has been shown that gas phase etching can produce near optimal geometries which maximise the birefringence from the available expansion coefficient mismatch. Jacketting and on-line annealing has been used to enhance the already high values of birefringence by up to 40%. Finally, it has been shown that the fibres can be used over long lengths with one polarised mode suppressed and over short lengths as a fibre polariser. The fibres should find use in optical fibre sensors where the control of polarisation is essential.

ACKNOWLEDGEMENTS

The authors would like to thank Professor A. W. Snyder, Dr. K. Okamoto and Dr. A. Ourmazd for interesting discussions and S. B. Poole for his invaluable help with measurements. A Research Fellowship (DNP) was provided by Pirelli Cable Company plc and a Research Studentship (MPV) by British Aerospace plc.

REFERENCES

1. Sasaki, Y., Okamoto, K., Hosaka, T., and Shibata, N., 1982, Proc. Of Optical Fibre Conf., Phoenix, Arizona, pp. 54-56.
2. Dyott, R. B., Cozens, J. R., Morris, D. G., 1979, Electron. Lett., 15, 380-383.
3. Varnham, M. P., Payne, D. N., Barlow, A. J., and Birch, R. D., June 1983, to appear in IEEE J. Lightguide Tech.
4. Birch, R. D., Payne, D. N., and Varnham, M. P., 1982, Electron. Lett, 18, 1036-1038.
5. Katsuyama, T., Matsumura, H., and Suganuma, T., 1981, Electron. Lett., 17, 473-474.
6. Ourmazd, A., Birch, R. D., Varnham, M.P., and Payne, D. N., 1983, Electron. Lett., 19, 143-144.
7. Snyder, A. W., and Ruhl, F., 1983, submitted to Electronics Letters.
8. Varnham, M. P., Payne, D. N., Birch, R.D., and Tarbox, E. J., 1983, submitted to Electronics Letters.



(b)

Figure 1 Design of Bow-Tie fibres

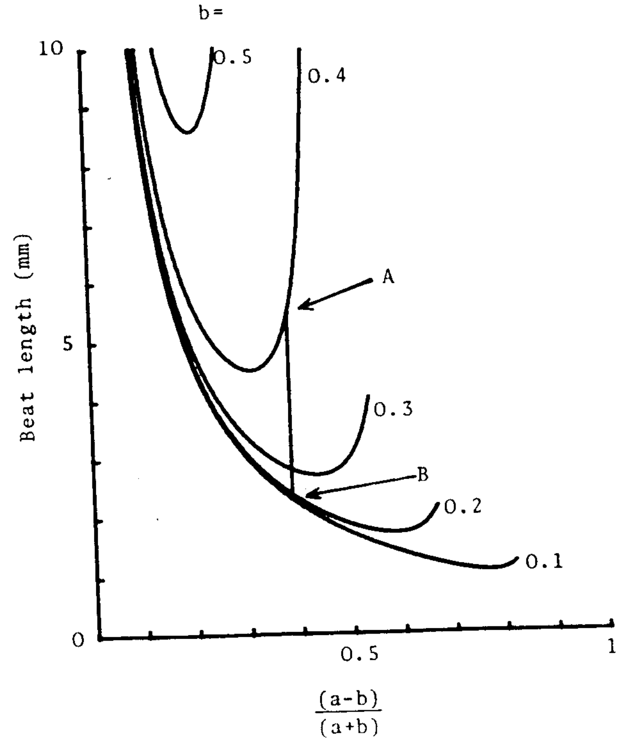
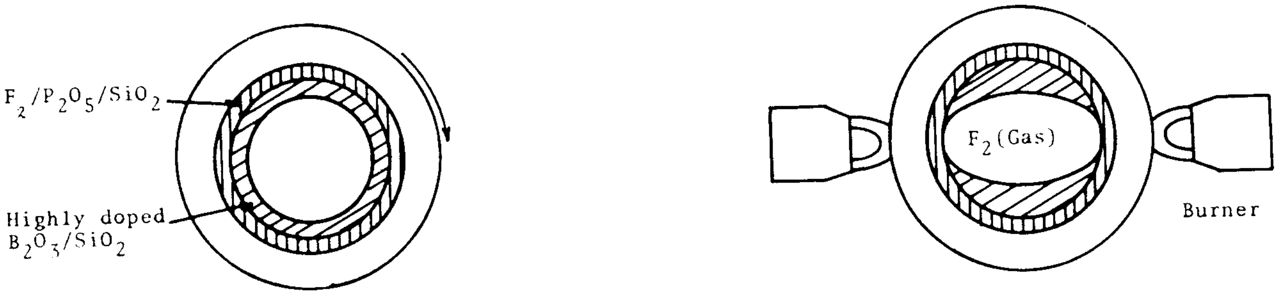
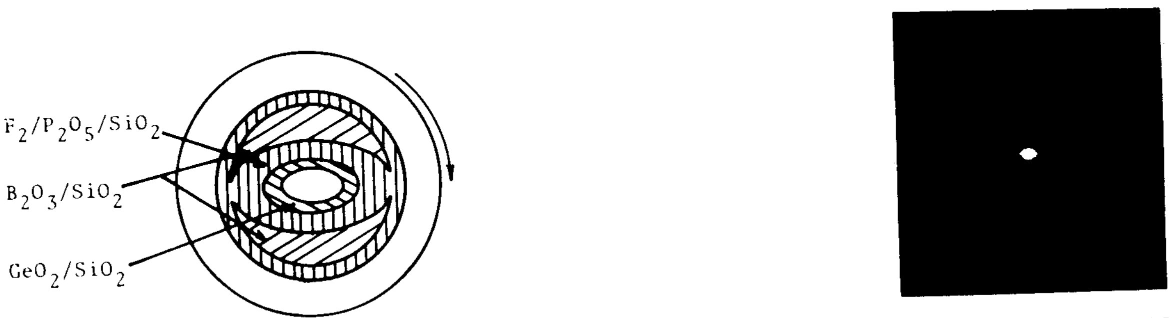


Figure 2 Design curves for Bow-Tie fibres



(a) Deposit

(b) Etch with florine



(c) Deposit

(d) Final cross-section

Figure 3 Schematic diagrams showing four stages of fabrication

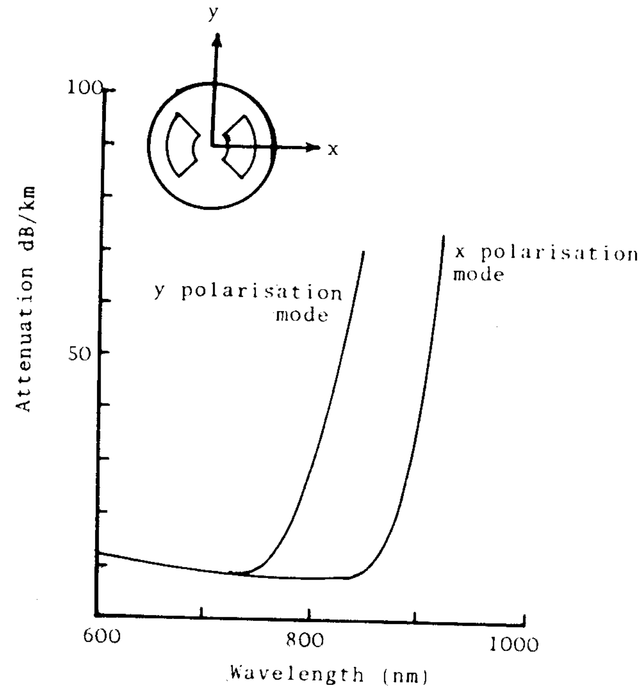


Figure 4 Attenuation curves for x and y polarised modes

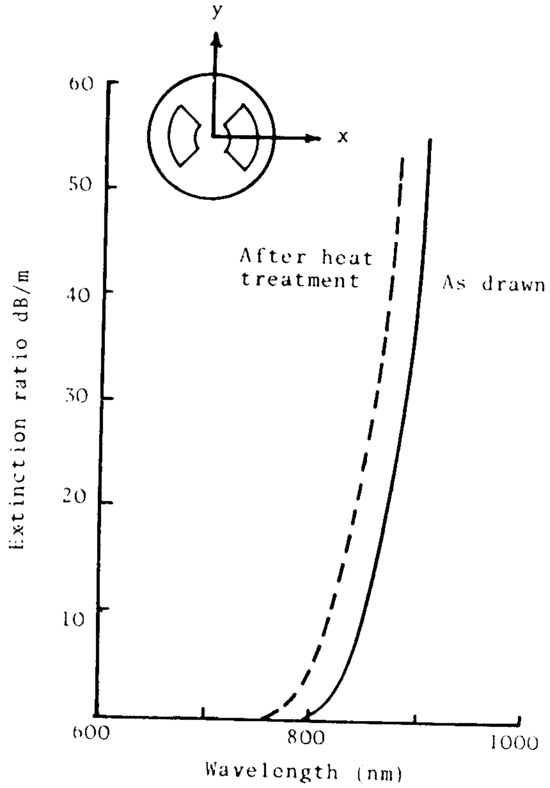


Figure 5 Extinction ratio of a Bow-Tie fibre before and after heat treatment