PRODUCTION OF SINGLE-MODE FIBRES WITH NEGLIGIBLE INTRINSIC BIREFRINGENCE AND POLARISATION MODE DISPERSION

Indexing terms: Optical fibres, Optical properties

Spinning the preform during drawing produces a fibre with a permanent twist. It is shown that such a fibre has negligible polarisation birefringence and rotation. Polarisation mode dispersion is similarly reduced.

Introduction: Single-mode fibres with controlled polarisation characteristics are required for a number of applications, e.g. the Faraday current monitor[1] and other fibre sensors. Moreover, for long-distance high-bandwidth telecommunications systems fibre birefringence is of interest, since it gives rise to polarisation mode dispersion, the magnitude of which can be significant, particularly when the birefringence is large.[2] In this letter, we report a method whereby fibres can be reproducibly manufactured with negligible intrinsic birefringence or polarisation mode dispersion. Such fibres will find application in the Faraday current monitor and for high-bandwidth telecommunications. The fibres are produced by rotating the preform during drawing to impact a permanent twist and are referred to as 'spun fibres' to distinguish them from fibres twisted after drawing. Results are presented which illustrate the dramatic reduction in both birefringence and polarisation dispersion which may be obtained by this technique.

Theory: In a single-mode fibre, birefringence arises from a difference $\Delta\beta$ in the propagation constants of the two orthogonally polarised fibre modes. This difference is caused by a combination of core ellipticity (form birefringence) and an associated thermal stress asymmetry (stress birefringence).[3] The fibre can conveniently be modelled as a series of birefringent plates with their principal axes aligned along the elliptic axes of the fibre.[4] If we spin the preform during drawing at a rate ξ rad/m, the azimuth of the fibre elliptic cross-section and hence the principal axes precess. The fibre can now be considered as being composed of individual local sections having a length of a quarter twist period and with alternating birefringence values. Thus, although each local section may have a relatively high birefringence $\Delta\beta$, its effect is compensated by the next, rotated, section. The overall effect[5] is to produce an apparent birefringence $R(z)$ which oscillates between a small positive and negative value along the fibre length z:

$$R(z) = 2 \sin^{-1}\left[\frac{\Delta\beta}{\sqrt{(4\xi^2 + \Delta\beta^2)}} \sin\left[\tfrac{1}{2}\sqrt{(\Delta\beta^2 + 4\xi^2)}z\right]\right] \quad \text{rad/m} \tag{1}$$

If the spin rate is large compared to $\Delta\beta$, the magnitude of the birefringence oscillations becomes negligibly small and the apparent birefringence is

$$R(z) = \frac{\Delta\beta}{\xi} \sin \xi z \quad \text{rad/m} \tag{2}$$

Thus the birefringence is reduced by the ratio of the spin pitch to the birefringence beat-length.

Note that a torsional stress exists in a fibre twisted after drawing[6] and this gives rise to a large circular birefringence owing to the photoelastic effect. By contrast, a fibre spun during drawing is in a viscous state and thus cannot support significant shear stress. The fibre exhibits no circular birefringence and appears isotropic if the spin rate is sufficiently large.

In a similar manner, the time-delay difference $\Delta\tau_0 = z/c \cdot d(\Delta\beta)/dk$ between the linearly polarised normal modes of a conventional fibre can be reduced by a factor which depends on the spin rate (c is the velocity of light, k the free space wavenumber). In the limit of large spin, the normal modes of the fibre become circularly polarised and the delay difference $\Delta\tau_s$ is[5]

$$\Delta\tau_s = \frac{\Delta\beta}{\xi} \Delta\tau_0 \tag{3}$$

For a fibre twisted after drawing, the induced circular birefringence is itself dispersive[7] and thus the fibre has no significant dispersion advantage over a typical untwisted one.

Fabrication of spun fibres: A preform made by the MCVD process is attached to the shaft of a gimbal-mounted speed-controlled DC motor which is fitted to the drawing tower in place of the normal preform chuck. A spring-loaded iris diaphragm is used to centre the lower end of the preform as it enters the graphite-resistance furnace and also serves as a furnace gas seal. Fibre drawing is commenced in the normal way and, once stable conditions are established, the motor is run up to the desired speed. Rotation rates as high as 2000 RPM have been achieved with an accurately centred, straight preform, giving a spin pitch of 1·5 cm for a drawing speed of 0·5 m/s. Shorter spin pitches (~ 1 mm) have been achieved at lower drawing speeds.

It has been found that the primary-coating process and diameter feedback control system are unaffected provided the spin rate is sufficiently high. The spin speed is linked to the fibre drawing speed to provide a constant spin pitch despite variations in drawing speed caused by automatic diameter control.

Results: The marked effect of spinning on the birefringence properties of four fibres is illustrated in Table 1. Values for the retardation and rotation are given for two adjacent sections of each fibre, one unspun and the other with the spin period shown. The polarisation properties were measured using crossed polarisers and a Soleil compensator, with the fibre suspended vertically in order to reduce the effects of external stresses. For the spun fibres a reduction in linear birefringence approaching two orders of magnitude has been achieved. The technique has been found to consistently reduce the retardation and circular rotation to levels at or below the measurement limit and has not resulted in a measurable increase in fibre attenuation.

The effect of fibre spinning on polarisation mode dispersion was estimated by determining the variation of fibre polarisa-

Table 1 COMPARISON OF BIREFRINGENCE IN UNSPUN AND SPUN FIBRES

Fibre number		Unspun fibre	Spun fibre	Fibre spin pitch
337	retardation	450°/m	2·3°/m	
(633 nm)	rotation	~ 50°/m	~ 0°/m	5·0 cm
302	retardation	60°/m	< 1°/m	
(633 nm)	rotation	4·3°/m	~ 0°/m	1·0 cm
333	retardation	—	< 2°/m	
(1064 nm)	rotation	—	~ 0°/m	3·9 cm
319	retardation	232°/m	< 4°/m	
(1064 nm)	rotation	1·1°/m	0·4°/m	0·92 cm
319	retardation	208°/m	~ 4°/m	
(1300 nm)	rotation	4°/m	0·6°/m	0·92 cm

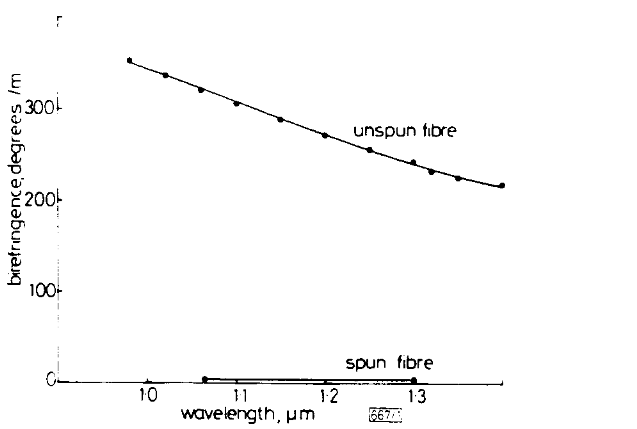

Fig. 1 *Variation of birefringence with wavelength in a typical fibre (upper curve) and in a spun section (lower curve)*

tion properties with wavelength. Raman generation in a single-mode fibre pumped with a Q-switched Nd:YAG laser was used as a tunable-wavelength source and the birefringence $\Delta\beta$ and the rotation in the test fibre measured as above. A typical result for the retardation is shown in Fig. 1 (upper curve) for an unspun fibre. The polarisation mode dispersion $\Delta\tau = z/c \, . \, d(\Delta\beta)/dk$ is estimated by fitting a curve to the data and taking the derivative with respect to wavelength. In the case of the spun fibre, both the retardation and rotation variations were at the limits of detection and consequently only two points are shown (Fig. 1, lower curve). The mode dispersion in this case was determined from the derivative of the variation of rotation with wavelength, since the normal modes are now circularly polarised.

For the fibre shown in Fig. 1, the intrinsic polarisation mode dispersion at a wavelength of 1·2 μm was calculated to be 4·6 ps/km. When spun this was reduced to less than 0·02 ps/km, thus illustrating the large reduction possible with the technique.

Conclusions: Fibres with low intrinsic birefringence and rotation can be readily and reproducibly manufactured by spinning the preform during drawing. The effect is periodically to reverse the local birefringence such that it averages nearly zero along the fibre length. The considerable reduction which can be achieved in both birefringence and polarisation mode dispersion has been demonstrated.

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