FINITE CLADDING EFFECTS IN HIGHLY BIREFRINGENT FIBRE TAPER-POLARISERS

Indexing terms: Optical fibres, Polarisers, Birefringence

Experimental results show that the refractive index of the outside medium affects the performance of fibre polarisers made by tapering high-birefringent bow-tie fibres. Both narrowband and wideband polarisers have been constructed having extinction ratios of 35 and 26 dB, respectively.

Introduction: The realisation of high-performance fibre polarisers is of considerable importance for polarimetric and interferometric fibre-optic sensors, such as the fibre-optic gyroscope.[1] To date the conventional approach has been to interact the field of a monomode optical fibre with a metal coating[2] or with a birefringent crystal.[3] The effect is to cause one polarised mode to cut off while leaving the other mode relatively unattenuated. However, recently it has been shown[4,5] that when highly birefringent fibres are operated at low V-values the two polarised modes have different degrees of guidance. Thus polarising action can be produced by operating the fibres at a wavelength where the V-value is low and inducing bending or microbending.[6] The same effect can be achieved by lowering the fibre V-value locally using the diameter reduction which occurs in a taper.[7]

Although both bending and tapering represent a considerable advance in fibre polariser fabrication, Villarruel *et al.*[7] have shown that the taper approach has some inherent advantages, namely: (i) smaller size; (ii) decreased lead sensitivity to bending; (iii) the possibility of in-line fibre polarisers in the gyro. The performance of their taper polarisers was, however, relatively low (15 dB extinction ratio) and it was therefore necessary to concatenate four tapers to produce an extinction ratio of 30 dB with 3 dB insertion loss.[7]

The purpose of the present work is to show that the existence of a finite cladding dramatically influences the performance of a taper polariser. In particular: (i) coupling between the core modes and discrete, lossy cladding modes has been observed, an effect which is bend-sensitive and has resulted in extinction ratios as high as 35 dB; (ii) the extinction ratio has been found to depend critically on the refractive index of the outside medium. In addition, our taper polarisers have higher extinction ratios than those of Villarruel,[7] a property which we attribute to the use of bow-tie fibres.[8]

Experimental: Taper polarisers were made by heating a short section of bow-tie fibre[8] and stretching until the optical throughput fell by a specified amount (e.g. 50%), the choice depending on the required wavelength of operation. The 77 μm-diameter bow-tie fibre used for the following experiments had depressed bow-tie sections, a beat length of 0·9 mm at 633 nm and a cutoff wavelength of 600 nm.

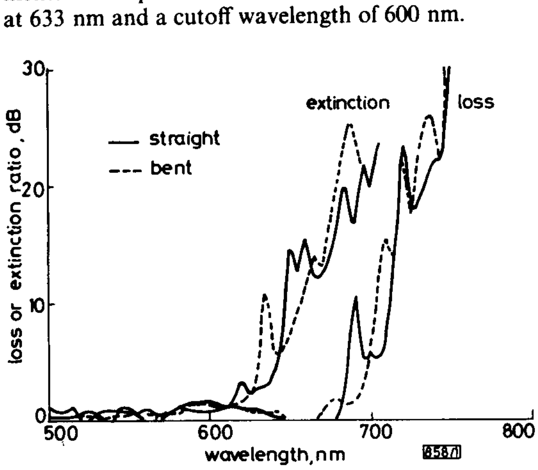

Fig. 1 *Spectral guided-mode loss and extinction ratio measured in a straight taper polariser (solid curves) and bent taper polariser (broken curves)*

Fig. 1 (solid curves) shows the extinction ratio and guided-mode loss of a taper polariser against wavelength. The 10 mm-long reduced fibre section was 59 μm in diameter and had 10 mm-long entry and exit tapers. It can be seen that both modes suffer increasing losses with increasing wavelength as the guidance of each polariser mode reduces. Owing to its weaker guidance, the y-polariser mode becomes lossy at shorter wavelengths than the x-polarised mode, giving a wavelength window in which polarising action occurs. The untapered fibre performs similarly but at much longer wavelengths (750 nm) where the V-value is correspondingly low.

The leakage edges exhibit oscillations which can be attributed to coupling between the core modes and cladding modes guided by the cladding/air interface. To determine whether the modes are actually cut off in the reduced-diameter region or whether the loss edges are caused by sharp transitions within the taper, the polariser was bent ($R \simeq 50$ mm) and the measurement repeated. If the modes were approaching cutoff in the small-diameter section, the application of a bend would be exposed to shift the loss edges to shorter wavelengths, since the modes would then leak prematurely.[6] The leakage edges of the bent taper are shown by the broken lines in Fig. 1. It is clear that bending has not caused any significant shift in the leakage edges, implying that the taper itself induces mode losses which exceed those experienced in the reduced-diameter section, and that the modes do not experience cutoff. However, bending has altered the coupling to the discrete cladding modes, as evidenced by the wavelength shift in the position of the oscillations. These oscillations are in reality much sharper than shown in Fig. 1, where they have been smoothed by the white-light measurement system ($\Delta\lambda \sim 5$ nm). When using monochromatic light from a helium-neon laser we have observed extinction ratios as high as 35 dB with 2·5 dB insertion loss, the performance of the polariser being tunable by bending the polariser.

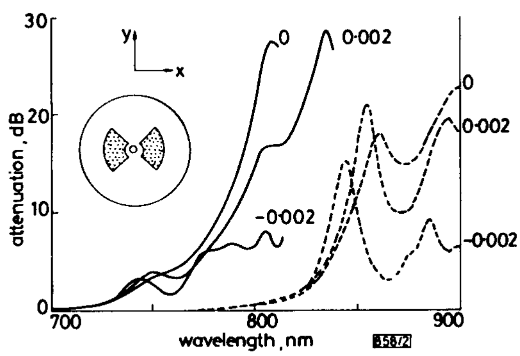

Fig. 2 *Spectral attenuation curves for the x- and y-polarised modes in a bow-tie taper polariser placed in oils having different refractive indices*

The indices are given with respect to silica

Fig. 2 shows the effect of placing another taper polariser in oils having different refractive indices. Losses for both x- and y-polarised modes are shown with the index of the oil higher, lower and matched to the silica substrate. The best average performance of the polarisers is obtained when the oil refractive index is matched to silica. For this condition at 810 nm, a broadband source (10 nm) would experience an extinction ratio of 26 dB and a guided-mode loss less than 2 dB. These values are better than those quoted in Reference 7, an effect which we attribute to the use of a fibre which is designed for polarising applications, rather than to any differences in fibre-polariser fabrication techniques. Consequently, further improvement is expected as the design and fabrication of polarising fibres is improved.

The extinction ratio at 810 nm is plotted against the oil refractive index expressed relative to silica in Fig. 3. For refractive indices less than silica the extinction ratio is approximately constant at 7 dB, rising sharply to 26 dB at the matching condition. Increasing the refractive index above that of silica leads to a gradual reduction in performance. The effects when not index-matched can both be attributed to reflections at the taper/oil interface which trap the power radiating from the unwanted polarisation. Thus the total internal reflection when the oil has a lower refractive index has a much larger effect than the smaller Fresnel reflections which occur when the oil has a higher refractive index. Further evidence

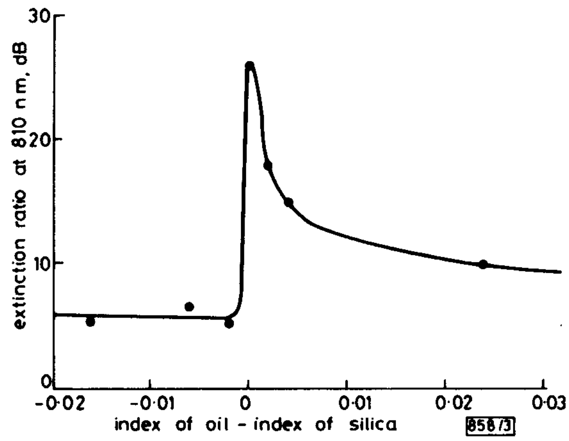

Fig. 3 *Extinction ratio measured at 810 nm shown as a function of the refractive-index difference between the oil and the silica substrate*

for this model is provided by the complete absence of oscillations in the attenuation curves (Fig. 2) for the matched-index case when no reflections can take place.

Conclusions: Finite cladding effects have been observed in taper polarisers made from highly birefringent bow-tie optical fibres. Two effects occur: first, oscillations are observed in the attenuation curves of each polarised mode; secondly, we find a dependence of extinction ratio and guided mode loss on the refractive index of the outside medium. The oscillations are due to coupling to discrete lossy cladding modes, are bending-tunable and can be utilised to make high extinction polarisers (35 dB) suitable for narrow-linewidth lasers. The dependence of extinction ratio on the outside medium is caused by reflections at the fibre/oil interface. Optimum performance for broadband source (10 nm) is obtained when the taper is index-matched and a taper polariser having an extinction ratio of 26 dB and guided mode loss of 2 dB has been demonstrated.

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