ALL-FIBRE POLARISING BEAMSPLITTER

Indexing terms: Optical fibres, Optical connectors and couplers

The first fibre equivalent of a polarising beamsplitter is reported. The device is based on a fused-taper fibre coupler. Separation of the orthogonally polarised components of the input light can be accomplished to better than 17 dB.

Introduction: Monomode fibre couplers are key components in many sensor and communication applications, with uses ranging from general-purpose 3 dB optical-power splitters[1] to wavelength multiplexers.[2,3] More specialised couplers for polarisation control can also be fabricated using birefringent fibres. Thus polarisation-maintaining couplers have been fabricated[4] and couplers which transmit only one plane of polarisation[5] have been fabricated from polarising fibre.[6]

Recently, we reported on the properties of very long fused-taper couplers[7] having interaction lengths up to 600 mm, fabricated from conventional single-mode fibres. These couplers have many interesting and novel properties. In particular, we demonstrated the first fibre equivalent of a polarising beamsplitter (a fibre 'Wollaston prism'), and the concatenation of couplers to construct narrowband optical filters.

The purpose of this letter is to report the performance of the fibre polarising beamsplitter in detail. In particular, the spectral power-splitting ratio for each of the orthogonally polarised modes is measured and the input and output polarisation extinction ratios of the polarising beamsplitter are investigated.

Spectral response: The spectral power-splitting ratio of a coupler with a 200 mm-long fused region was measured using a white-light/monochromator arrangement, and is shown in Fig. 1. The coupler has a loss of less than 1 dB and was fabricated from conventional matched-cladding fibres with a cutoff wavelength at 615 nm. As observed by other workers the spectral response is oscillatory, implying that there are multiple power exchanges between fibres along the length of the coupler. As expected, close observation also reveals that the wavelength separation between successive maxima is smaller at longer wavelengths.

A previously unreported feature illustrated in Fig. 1 is that the oscillatory coupling response is modulated by a sinusoidal envelope having peaks at 750 nm and 1000 nm and a zero at 880 nm. The explanation is that the orthogonally polarised eigenstates of the coupler have slightly different coupling strengths. Thus the spectral oscillation period of the coupling ratio differs slightly for the two polarisation states and, in a long coupler with many power exchanges, this leads to phase slippage between the two responses. If the coupler is sufficiently long, complete 'dephasing' is possible, and one polarisation can experience nearly 100% power transfer at the output, while the other has none. This condition corresponds to the null observed in Fig. 1, at which wavelength the unpolarised input light is equally divided into its two orthogonally polarised components at the output ports.

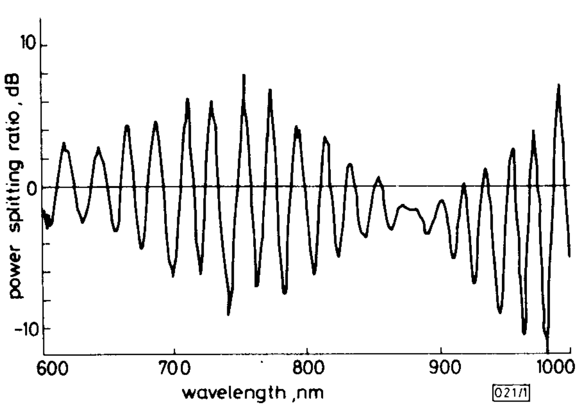

Fig. 1 *Spectral response of power splitting ratio in an overcoupled 4-port fibre coupler*

If the spectral periods of the coupling response of the two polarised modes of the coupler are $\Delta\lambda_1$ and $\Delta\lambda_2$, then the spectral response $R(\lambda)$ will be given by

$$R(\lambda) = \cos\left(\frac{2\pi}{\Delta\lambda_1}\lambda\right) + \cos\left(\frac{2\pi}{\Delta\lambda_2}\lambda\right) \quad (1)$$

where $R(\lambda)$ is the ratio of power in the two output ports and $\Delta\lambda_1 \simeq \Delta\lambda_2$. This is almost exactly the response shown in Fig. 1.

The above explanation has been verified experimentally. The linearly polarised eigenmodes of the coupler were individually selected by placing a polariser in the input port, tuning the wavelength to 880 nm, and then varying the angle of the input polariser until a null was observed at the throughput port. The wavelength and polariser angle were then successively adjusted to operate at the wavelength where the coupling responses for the two polarisations were precisely in antiphase, i.e. at the coupling null of 880 nm in Fig. 1. The spectral response of the coupling ratio was then measured for both this polarised mode and, subsequently, for its orthogonal partner. The results are shown in Fig. 2*a* by the solid and broken lines, respectively. We now see that the coupling ratio for each polarisation behaves conventionally, giving an oscillatory spectral response which is substantially unmodulated. Furthermore, the difference in spectral periodicity for the two polarisations can be clearly seen, and we note that the orthogonal linear polarisations are coupled to opposite output ports at 880 nm, whereas the device is polarisation transparent (i.e. appears isotropic) at 750 nm.

In the original experiment shown in Fig. 1, unpolarised input light was used and the output detectors simply summed the responses for both polarisations. As a further verification of the coupler operating mechanism, this summation has been performed numerically on the measured data of Fig. 2*a*. The result, Fig. 2*b*, is indeed virtually identical to Fig. 1, conclusively showing that the difference in coupling length between the two polarised modes in the couplers leads to the observed modulated spectral response.

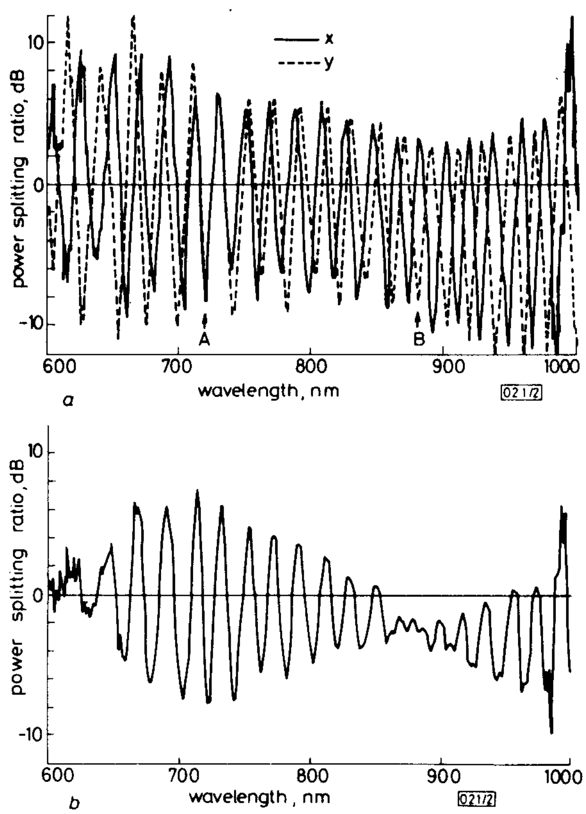

Fig. 2

a Spectral response of the coupler of Fig. 1 when excited with light having *x*-polarisation (solid lines) and *y*-polarisation (broken lines)
b Numerical addition of the two spectral responses shown in (*a*). Note the similarity to Fig. 1

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The difference in coupling between the two polarised modes in the coupler arises as a result of birefringence in the fused, tapered coupling region. The birefringence has two sources: (i) the geometric birefringence produced in a twin-core fibre (i.e. the coupler) owing to its inherent lack of circular symmetry, and (ii) the anisotropic thermal stress caused by the difference in expansion coefficients between the two cores and the silica cladding. To determine which of these sources is the stronger requires further analysis.

Polarising beamsplitter: The operation of overcoupled couplers as polarising beamsplitters can now be described. Referring to Fig. 2*a*, we see that at 880 nm the coupler transmits x-polarised light at the throughput and y-polarised light at the crosscoupled port. The coupler is therefore the fibre equivalent of a bulk-optic polarising beamsplitter, such as a Wollaston prism. More detailed measurements on the device using a tungsten lamp/monochromator with a polariser at the input port revealed a polarisation-splitting ratio of 17 dB between the two output ports. This measurement represents the limit of our current measurement range, and the true polarisation extinction ratio of the coupler is therefore likely to be > 17 dB. The polarisation extinction ratios measured directly at the output using unpolarised light at the input are not as good, however, being 4 dB and 17 dB for the throughput and crosscoupled ports, respectively. The fact that the output extinction ratios are not identical is somewhat surprising, but was previously predicted theoretically by Burns *et al.*[8] in an idealised birefringent coupler.

It should be noted that the polarising beamsplitter reported here does not have the ability to preserve a polarisation state, owing to the use of conventional (nonpolarisation-maintaining) fibres for the leads. This can be overcome by jointing polarisation-maintaining fibre leads close to the coupling region. Moreover, in many applications the requirement is to analyse a state of polarisation without regard to the output state of polarisation. For example, in polarimetric sensors we simply require the measurement of the relative intensities at $\pm 45°$ to the axis of birefringence of the sensor fibre.

The thermal stability of the polarising beamsplitter reported here has been measured and found to be stable over the temperature range 20°C to 70°C.

Conclusions: The spectral power splitting ratio of a 200 mm-long fused-fibre coupler has been measured and found to be oscillatory with a sinusoidal envelope. The modulation envelope arises because the orthogonally polarised modes experience different coupling strengths within the coupler and this has been experimentally verified. A wavelength region exists where the two polarisation states appear at different output ports, and this has allowed the construction of the first fibre polarising beamsplitter. The device has low loss and can separate the input polarisation states by more than 17 dB.

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