AN ALL-FIBRE POLARISING BEAM SPLITTERS AND SPECTRAL FILTERS

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Introduction

Monomode fibre couplers are key components in many sensor and communication applications, with uses ranging from general-purpose 3dB 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 600mm, fabricated from conventional single-mode fibres. 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 the present work is to report the performance of the fibre polarising beamsplitter and the narrowband filter in detail, with particular emphasis on polarisation extinction ratio and filter spectral bandwidth.

Polarising Beamsplitter

The spectral power-splitting ratio for unpolarised light of a coupler with a 200mm long fused region, measured using a white light/ monochrometer arrangement, is shown in Figure 1. The coupler has a loss of less than 1dB and was fabricated from conventional matched-cladding fibres with a cut-off wavelength at 615nm. 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.

A previously unreported feature is that the oscillatory coupling response is modulated by a sinusoidal envelope having peaks at 750nm and 1000nm and a zero at 880nm. The explanation is that the orthogonally-polarised eigenstates of the coupler have slightly different coupling strengths and the spectral oscillation period of the coupling ratio therefore differs slightly for the two polarisation states. In a long coupler with many power exchanges, this leads to phase slippage between the two responses. If the coupler is sufficiently long, complete de-phasing 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 Figure 1, at which wavelength the unpolarised input light is equally divided into its two orthogonally-polarised components at the output ports.

Experimentally, this was verified as follows. The linearly-polarised eigen modes of the coupler were individually selected by placing a polariser in the input port, and tuning the wavelength to 880nm where the coupling responses for the two polarisations are precisely in antiphase. The spectral response of the coupling ratio was then individually measured for both polarised modes. The results are shown in Figure 2 by the solid and dashed 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 880nm, whereas the device is polarisation transparent (i.e. appears isotropic) at 750nm. A numerical summation of the two responses shown in Figure 2 gives almost exactly the response for unpolarised light given in Figure 1.

At 880nm, more detailed measurements of the polarisation splitting ratio between the two output ports gave a measurement-limited figure of >17dB.

<u>Narrow-Band Filter</u>

The spectral response $P(\lambda)$ of a highly-overcoupled 4-port coupler is approximately sinusoidal with wavelength period $\Delta\lambda$, where $\Delta\lambda$ depends on the coupling strength. If two or more couplers are concatenated (inset Figure 3), the throughput will be given by

$$P(\lambda) = \left[1 + \sin\left(\frac{2\Pi\lambda}{\Delta\lambda_1} + \theta_1\right)\right]\left[1 + \sin\left(\frac{2\Pi\lambda}{\Delta\lambda_2} + \theta_2\right)\right] \qquad (1)$$

where $P(\lambda)$ is the power in the output port, $\Delta\lambda_1$, $\Delta\lambda_2$ are the channel spacings of the 1st, 2nd couplers and θ_1 and θ_2 are the phase parameters of the couplers. From equation (1), the spectral throughput of two concatenated couplers was calculated for $\Delta\lambda_1 = 2(\Delta\lambda_2) = 100$nm and $\theta_1 = \theta_2 = 0$. The result, Figure 3 shows a spike filter characteristic. Such a filter could be used for example, as a wavelength drop-off filter in a wavelength-division multiplexed communication link, or to separate a single line from a multi-longitudinal mode laser.

An optical bandpass filter was fabricated from two concatenated overcoupled monomode fibre couplers which have 20mm and 150mm interaction lengths respectively. To avoid the necessity of splicing the couplers together, they were made in succession on the same fibre. The spectral throughput of this dual-coupler bandpass filter is also shown in Figure 3. At the centre wavelength, 650nm, the filter has a throughput of 95% (a loss of only 0.2dB) and a 3dB spectral width of 20nm. The two side lobes at 620nm and 675nm are present at 25%. Close agreement with the calculated curve is observed.

Preliminary measurements of the thermal stability of both the polarising beamsplitter and the narrow band filter in the temperature range 20°C-70°C has shown that their wavelength characteristics can be surprisingly stable.

Conclusions

The spectral power splitting ratio of a 200mm-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 17dB.

The concatenation of fused taper couplers to make optical bandpass filters has been described and the response of a dual coupler filter calculated. A low-loss filter was successfully fabricated from two couplers having 20mm and 200mm interaction lengths respectively. The filter had a throughput of 95% and a 3dB bandwidth of 20nm. The potential bandwidth of these filters is much smaller, a 300mm-long coupler having a measured channel spacing so narrow as to make measurement difficult. Improved fabrication control should provide the ability to tailor a number of different responses using multiple-coupler arrangements.

References

1. Kawasaki, B.S., Hill K.O., Lamont, R.G.: "Biconical-taper single-mode fibre coupler", Opt. Lett., 1981, 6, pp.327-328.

2. Digonnet, M. and Shaw, H.J.: "Analysis of tunable single-mode optical fibre coupler", IEEE J. Quant. Electron., 1982, QE-18, pp. 746-754.

3. Ragdale, C.M., Payne, D.N., de Fornel, F.: "Single-mode fused biconical couplers", Proc. 1st Int. Conf. on Optical Fibre Sensors, London, 1983.

4. Kawachi, M., Kawasaki, B.S., Hill, K.O., Edahiro, T.: "Fabrication of single-polarisation single-mode fibre couplers", Electron. Lett., 1982, 18, pp. 962-964.

5. Yokohama, I., Okamoto, K., Kawachi, M., Noda, J.: "Polarising fibre coupler with high extinction ratio", Electron. Lett., 1984, 20, pp. 1004-1005.

6. Varnham, M.P., Payne, D.N., Birch, R.D., Tarbox, E.J.: "Single polarisation operation of highly-birefringent Bow-Tie optical fibres", Electron. Lett. 1983, 19, pp. 246-247.

7. Yataki, M.S., Varnham, M.P., Payne, D.N.: "Fabrication and properties of very-long fused taper couplers", Proc. 8th Optical Fibre Conference, San Diego, 1985.