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LOW-LOSS PLANAR OPTICAL POLARISATION SPLITTER WITH SMALL DIMENSIONS

Indexing terms: Integrated optics, Optical receivers, Optical waveguide components, Polarisation

A novel planar polarisation splitter with the smallest dimensions thus far reported (0.6 x 2.5 mm²) is presented. The component, which is based on an optical phased array, was designed and fabricated using conventional (high-quality) optical lithography. Insertion losses as low as 0.5 dB and crosstalk values of 17–21 dB have been achieved.

Introduction: Polarisation splitters play an important role in coherent optical receivers based on polarisation-diversity detection schemes. Planar splitters based on intersecting waveguides, focusing gratings, directional couplers and two-mode interference couplers have been reported recently.1–3 The best results obtained are 1.7 dB insertion loss and 20 dB far-end crosstalk. The smallest device length so far reported is 5 mm. In this letter a new planar polarisation splitter with comparable performance but considerably smaller device size will be presented.

Basic principle: Recently we reported a planar optical phased array, consisting of a number of concentrically bent waveguides with both focusing and dispersive properties.4 The component had considerable loss, however, as evidenced by the occurrence of multiple foci in the focal plane, which is characteristic for phased arrays. The power coupled to higher-order beams can be reduced by spacing the individual elements more closely. This can be achieved by providing the array with fan-in and fan-out coupling sections at both ends, as shown in Fig. 1. These sections gradually adapt the input- and output beams to the set of guided modes in the array. To obtain a smooth connection with the concentric section, an adaptor is required.

The phase transfer of the complete phased array (including coupling and adaptor sections) can be controlled by choosing the radii R₁ and R₂ of the concentric section such that the total length of each channel equals an integer number of wavelengths. This choice of the phase transfer will transform the divergent incoming beam into a convergent outgoing one with the same angular field distribution, so that the source field at the transmitter side will be reproduced in the focal plane at the receiver side. If the array is designed such that the length of the array channels increases linearly with their number, then a small variation of the propagation constant will result in a linear variation of the phase transfer, which will tilt the outgoing beam and thus lead to a lateral shift of the focal position.

Since the propagation constant in a planar waveguide depends on the polarisation as well as on the wavelength, the phased array can in principle operate as a polarisation splitter as well as a wavelength (de)multiplexer.

Polarisation splitter design and fabrication: A splitter design with a total device area of 0.6 x 2.5 mm² was analysed. The analysis was done by computing the two-dimensional diffraction field at the input plane, as indicated in Fig. 1. Next, it was assumed that the excitation coefficients of the modes in the individual waveguides of the array are proportional to the amplitude of the diffracted field at the origin of the waveguides. The coupling loss is computed by overlapping the diffraction field with the sum of the fields of the individual waveguide modes. The sum of these fields at the output plane was then used as the source field for the computation of the field in the focal plane. Finally, the focal field was overlapped with the modal fields in the receiver waveguides to obtain insertion loss and crosstalk figures.

The theoretically predicted insertion loss is 0.5 dB for both channels, if positioned symmetrically relative to the optical axis. Channel crosstalk is predicted to be better than −45 dB.

Four identical polarisation splitters were realised in a 2 μm-wide SiO₂/Al₂O₃/SiO₂ ridge-type waveguide structure on silicon substrate, described by Smit.7 Waveguide channels were formed by atom-beam-milling a 40 nm ridge in the aluminium oxide film. Because of the availability of an accurate measurement configuration operating at 633 nm (HeNe), a first splitter design was realised at this wavelength. Splitters operating at longer wavelengths can be realised equally well with comparable dimensions, the wavelength of 633 nm radiation in aluminium oxide being close to that of 1300 or 1500 nm radiation in GaInAsP, due to the high refractive index of the latter. Fig. 2 shows a micrograph of an experimental device. The two bent waveguides at each side of the phased array and the two straight waveguides are used as reference channels.

Experimental results: The devices were measured by selectively coupling TE- or TM-polarised light into the splitter with a coupling prism, and observing the light intensity in the output channels at the cleaved endface, indicated in Fig. 1. The light distribution is imaged onto a CCD camera with a microscope objective. Signal levels are measured by digitising the video image. Fig. 3 shows a photograph of the light distribution for TE- and TM-polarised light, and Fig. 4 an intensity scan across the TM distribution. The two channels furthest to the
left and the four furthest to the right are reference channels. Channels 3 and 4 from the left are the TE and TM channels, respectively. By making a comparison of the simultaneously excited reference channels with the splitter output channels, loss and crosstalk values can be determined.

![Image](image_url)

**Fig. 2 Micrograph of realised polarisation splitter**

Six reference channels are included, two bent channels on both sides of the splitter, and two straight ones. Array contains 26 waveguides.

![Image](image_url)

**Fig. 3 Light distribution at cleaved endface for TE and TM polarisations**

Channels 3 and 4 from left are TE and TM channel, respectively. Other channels are reference channels.

![Image](image_url)

**Fig. 4 Intensity scan across TM-polarised light distribution, shown in Fig. 3**

The measured insertion loss for the TM channel is equal to the theoretically predicted 0·5 dB within the accuracy of the measurement method, which is estimated to be ±0·5 dB. The TE channel has 1·0 dB additional loss, for reasons not yet understood. Channel crosstalk is 20 dB for the TM channel and 17 dB for the TE channel, which is close to the best results reported, but with a considerably smaller device size.

**Conclusions:** A new polarisation splitter based on an optical phased array is reported. A number of experimental devices were realised using conventional (high-quality) optical lithography, with 0·5–1·5 dB insertion loss and 17–20 dB crosstalk. These results are comparable with the best results reported so far, but with a considerably smaller device size (0·6 x 2·5 mm$^2$).

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**References**


**LOSSES IN SMALL-RADIUS BENDS IN SINGLE-MODE FIBRES**

**Indexing terms**: Optical fibres, Optical transmission, Refractive index profiles

Refractive index profiles and mode field radii determine small-radius bending losses in single-mode fibres. Losses in six different types of fibres were measured in bends with radii ranging from 1·25 to 8 mm. The results show that a refractive index depression in the core centre reduces the bending-loss sensitivity.

**Introduction:** Single-mode fibres with smaller mode field radii and, therefore, tighter confinement of the mode field should exhibit lower bending losses. However, bending tests conducted on six different types of single-mode fibres showed that a smaller mode field radius does not necessarily ensure lower losses for bending radii between 1·25 mm and 8 mm. For a given bending radius the measured losses depend on both the refractive index profile and mode field radius.

**Test results:** Fig. 1 shows the index profiles (measured at 0·63 mm) for the six fibres investigated. Depressions at the core centre due to GeO$\text{2}$ burn-off can be observed in fibres 1, 2 and 6. Reduced cladding and outer diameters in fibres 1, 2 and 3 allowed smaller bends than the conventional 125/250 mm diameters in fibres 4, 5 and 6. The cutoff wavelength $\lambda_c$, the maximum relative index difference $\Delta$ and the radial distance of the maximum core index from the axis $r_m$, are shown in Table 1.

The fibres were bent into semicircles with radii ranging from 1·25 mm to 8 mm and losses per unit length in the bend were measured over the spectral region from 1·30 to 1·60 mm. Fig. 2 shows the losses in dB/mm at 1·55 mm. The fibres exhibited strong spectral resonances which required the loss at 1·55 mm to be interpolated between resonant peaks. To investigate further the bending sensitivity, far-field intensities were measured by launching a 1·55 mm laser beam into the fibres and rotating a GaInAs pin diode in an arc in the output.