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Citation for published version (APA):
Dam, van, C., Staring, A. A. M., Jansen, E. J., Binsma, J. J. M., Dongen, van, T., Smit, M. K., & Verbeek, B. H. (1997). Elimination of ghost images in the response of PHASAR-demultiplexers. In *Proceedings : ECIO '97 : 8th European Conference on Integrated Optics and Technical Exhibition* (pp. 268-271). Royal Institute of Technology.

Document status and date:
Published: 01/01/1997

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
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Elimination of ghost images in the response of PHASAR-demultiplexers

C. van Dam, A.A.M. Staring*, E.J. Jansen*, J.J.M. Binsma*, T. van Dongen*,
M.K. Smit and B.H. Verbeek*

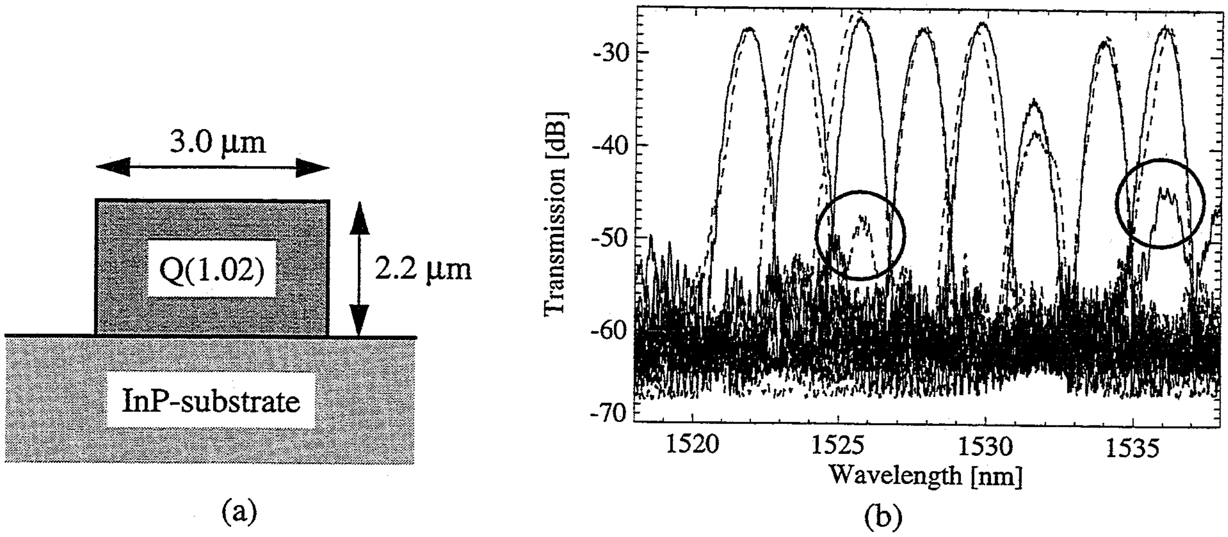
Delft University of Technology, Dept. of Electrical Engineering
P.O. Box 5031, NL-2600 GA Delft, The Netherlands
Phone: +31 - 15 - 2787089, Fax: +31 - 15 - 2784046, Email: C.vanDam@et.tudelft.nl
*Philips Optoelectronics Centre, Eindhoven, The Netherlands

Abstract

In this paper the occurrence of first-order modes in the performance of phased-array demultiplexers is investigated. It is found that they cause "ghost" images, which can be circumvented by optimising waveguide junctions.

Introduction

Usually, waveguides used in phased-array demultiplexers are monomode, or designed in such a way that the first order mode is close to cutoff or inhibits extremely high radiation loss. However, the designer not always has this freedom of choice, of which the raised-strip waveguide, as shown in figure 1a, with the proper aspect ratio (height/width) for polarisation independence is a good example [1,2]. Due to the high lateral contrast, the first-order mode also experiences low radiation loss in the curved waveguides. Using such a waveguide the PHASAR-response may show ghost images as shown in figure 1b (circles). In this paper the occurrence of these ghost images is investigated. It is verified that they are caused by the excitation of first-order modes in the phased array, which can be circumvented by optimising the junctions between straight and curved waveguides.



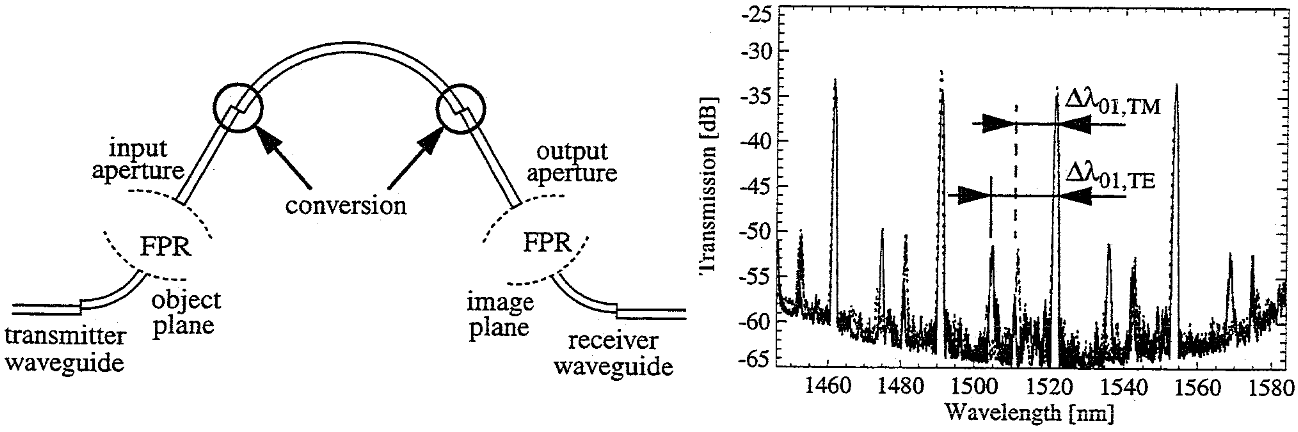
(a) (b)

Figure 1. Cross-section of the raised-strip waveguide (a), and ghost images in the response for TE (solid) and TM (dashed) polarisation (b).

Ghost image mechanism

The signals, converted to the first-order mode at junctions between straight and curved waveguides in the phased array (as depicted in figure 2a), focus in the image plane in the same way as the fundamental mode, but at a different position. This shift in position along the image plane corresponds to a shift in the wavelength response, and is due to the difference in propagation constants between the fundamental and first order mode, analogous to what is found for polarisation dispersion. Therefore this wavelength shift will be denoted as modal dispersion shift, and can be calculated in exactly the same manner as for the polarisation dispersion shift according to $\Delta\lambda_{01} \approx \lambda \cdot (N_0 - N_1)/\tilde{N}_0$, in which N_0 and N_1 are the effective indices for the fundamental and first-order mode, and $\tilde{N}_0$ is the group index. As the index of the first-order mode is smaller than the index of the fundamental mode, a positive modal dispersion shift is obtained, which means that the ghost image occurs at a shorter wavelength with respect to the original image. The predicted modal dispersion shift is 13.5 nm for TE polarisation, and 12.2 nm for TM polarisation.

Furthermore, the index difference between the first-order mode and the fundamental mode is smaller for TM polarisation than for TE polarisation. The result is that the modal dispersion shift for TM polarisation is smaller than for TE polarisation. This can be clearly seen in the graph of figure 2b. In this graph the response of one channel of a PHASAR demultiplexer (the same one of which the response is shown in figure 1b) is shown over the full wavelength span available from the tunable laser source. The modal dispersion shift is denoted by $\Delta\lambda_{01,TE}$ and $\Delta\lambda_{01,TM}$ for TE and TM polarisation, respectively. The measured values for the modal dispersion shift are $\Delta\lambda_{01,TE} = 16.0$ nm and $\Delta\lambda_{01,TM} = 10.8$ nm.

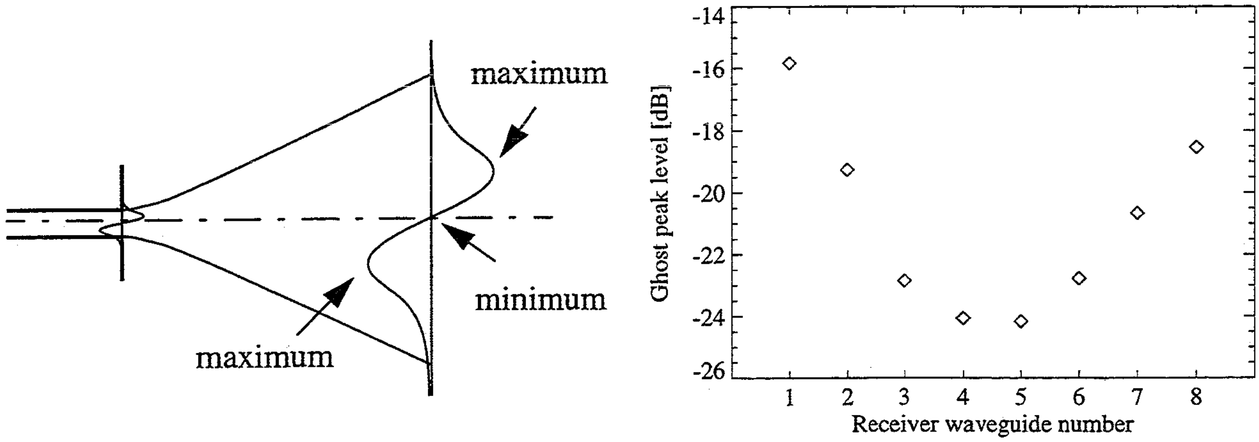


(a) (b)

Figure 2. Schematic diagram of a PHASAR-demultiplexer (a), and response over the full wavelength span of the tunable laser for TE (solid line) and TM (dashed line) polarisation (b).

The field obtained at the image plane is the sum-field of the far fields of all individual array waveguides. Therefore, if the wavelength is changed it will move through the image plane and follow the envelope described by the far-field of the individual array waveguides. In the case of a ghost image, this envelope has the shape of the far-field of the first-order mode. Figure 3a schematically shows the far-field of the first-order mode, which has the same shape as the modal field: two maxima with a minimum in the centre.

The assumption that ghost images originate from the presence of a first-order mode can therefore be verified by measuring the peak power in the ghost image with respect to the power in the original peak, for all receiver waveguides. As the receiver waveguides are placed in the centre of the image plane, the ghost peak level should have a minimum for the centre receiver waveguides, increasing towards the outer receiver waveguides. This can clearly be observed in figure 3b.



(a) (b)

Figure 3. The far-field of a first-order mode (a), and the ghost peak level with respect to the passband peak level for the eight output waveguides (b).

Junction optimisation

Mode conversion can be minimised by optimising the offset at the junctions on minimal first-order mode excitation. As only small corrections of the offset are needed, the bending radius nor the length of the straight section is changed, and therefore the phase transfer of the array is not influenced. As an example, we use the raised-strip waveguide with a thickness of 2.2 μm and a width of 3.0 μm, especially designed for polarisation independence for a Q(1.02) guiding layer [1,2], and a bending radius of 500 μm.

In figure 4a the efficiency of the coupling between the fundamental mode of the straight waveguide to the fundamental and first-order mode in the curved waveguide is shown. From this graph it can be seen that a first-order coupling efficiency to a TM-polarised mode of -25 dB is obtained if the offset is optimised to optimum coupling for the fundamental TE-polarised mode. An optimum offset cannot be found for both polarisations simultaneously, so that a compromise has to be made. This compromise can be found between the optimum offsets for each polarisation (120-150 nm). In the middle of this interval the maximum excitation of the first-order mode is below -30 dB for both polarisations, and the coupling loss for the fundamental order remains negligibly low.

Experimental results

An 8-channel raised-strip-waveguide-based PHASAR-demultiplexer with optimised junctions has been designed and fabricated. The channel spacing was designed 2.0 nm at a centre wavelength of 1536 nm. The array size is 1.0×1.3 mm^2, measured between object and image plane, and the overall device size is 1.3×3.2 mm^2, due to 250 μm separation of the input- and output waveguides needed in order to facilitate fibre-ribbon coupling. Low-pressure OMVPE has been used to grow the undoped guiding layer, and RIE using Cl_2 has been applied to etch the waveguides.

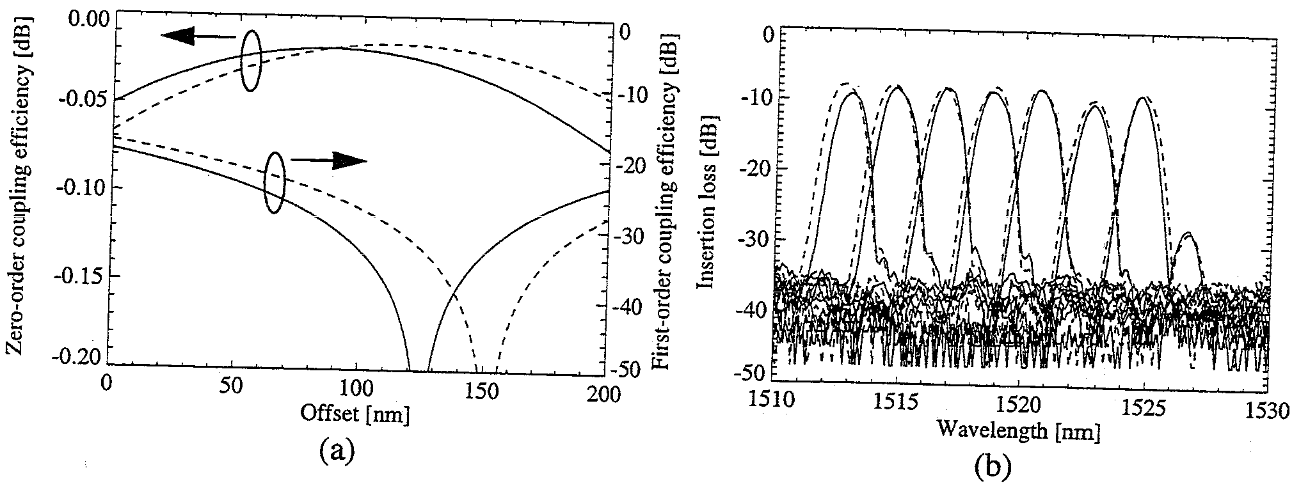


Figure 4. Zero and first-order coupling efficiencies (a), and measured wavelength response (b), both for TE (solid lines) and TM polarisation (dashed lines).

The response of the device was measured using a tunable laser, and is depicted in figure 4b. Light was coupled into the outermost input channel for both TE (solid lines) and TM polarisation (dashed lines). The crosstalk is better than -23 dB and the insertion loss is 8-10 dB (including the fibre-chip coupling loss of ±1 dB), of which 1.5 dB originates from the waveguide losses. As can be seen in the graph, no ghost images are observed.

Conclusions

In this paper the occurrence of first-order modes in the performance of PHASAR-demultiplexers has been investigated. It is found that they cause ghost images in the response, which can be circumvented by optimising waveguide junctions. This has been demonstrated using a raised-strip waveguide structure.

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