# Loss reduction for phased-array demultiplexers using a double etch technique

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## Introduction

Wavelength Division Multiplexing (WDM) is an effective technique to exploit the huge bandwidth of optical fibres. Key components in such WDM-systems are demultiplexers which spatially separate the different wavelength channels. Phased-array demultiplexers combine ease of fabrication and low insertion losses. Silica-based phased-array demultiplexers are realised with low losses from 2-3 dB [1,2]. InP-based demultiplexers show slightly higher on-chip losses of 4-6 dB [3,4]. In addition they have considerably higher fibre coupling losses (several dB's), but the advantage of InP-based demultiplexers is that they can be integrated with active components. Earlier we reported a low-loss demultiplexer with reduced fibre coupling loss by applying deeply etched InGaAsP waveguides with a relatively large core and a low index contrast, which had an almost circular mode profile [5]. The component had 4-5 dB on-chip loss and fibre coupling loss of about 1 dB to a tapered fibre. In this article we report a method to further reduce the on-chip losses.

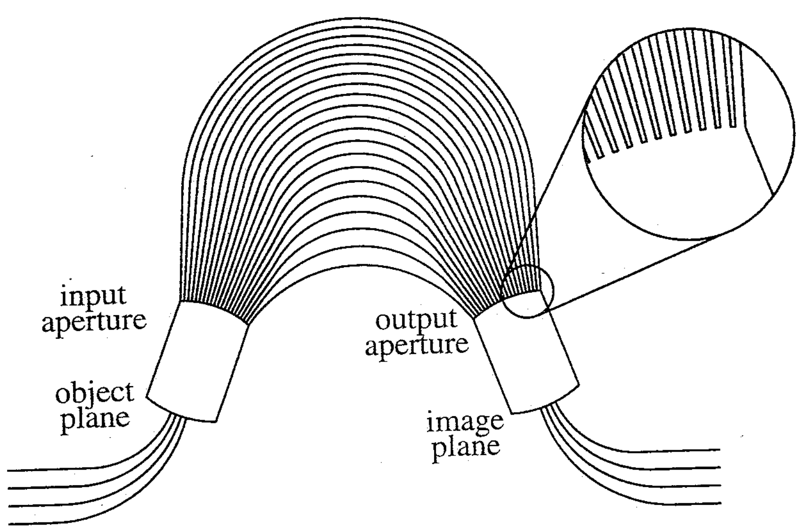


**Figure 1.** Schematic layout of the phased-array demultiplexer.

## Design

Most of the on-chip loss occurs at the junctions between the array and the slab guide, the so-called free propagation region (FPR), as shown in the inset of figure 1. At this junction the field in the waveguide section shows a very deep modulation (figure 2a, solid line) due to the deep trenches between the array waveguides.

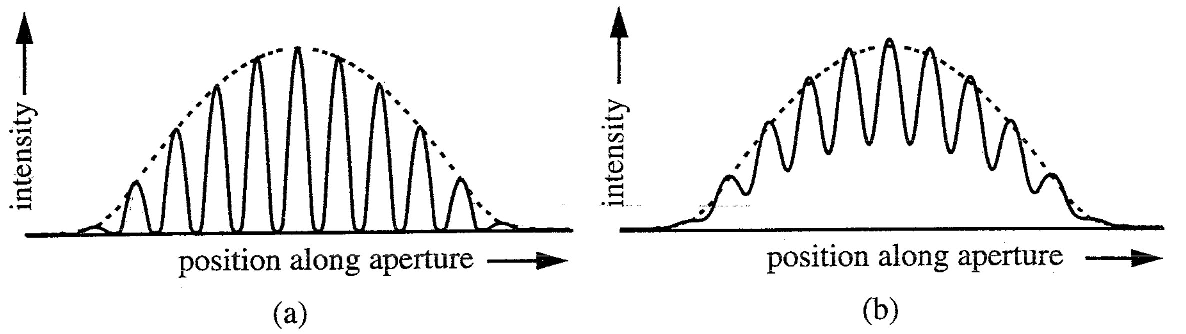


**Figure 2.** Fields at the aperture: sum field of the array waveguides (solid line), and the field required for efficient coupling to the receiver waveguide order (dashed line). In (a) the the fields are shown for the deeply etched waveguide structure. The coupling efficiency can be improved by a using a shallowly etched waveguide structure, as shown in (b).

The ripple in the field pattern causes a considerable fraction of the power to be radiated into adjacent orders. The dashed line depicts the field corresponding to the dominant order, which couples efficiently into a receiver waveguide. The coupling efficiency is found from the overlap of the two fields. The overlap is increased by filling the zeroes between the individual waveguide modes (figure 2b, solid line). This can be done by inserting a shallowly etched transition region (TR) between the deeply etched array waveguides and the FPR, as shown in figure 3. This method has been applied before to waveguide bends, in order to reduce the bending and scattering losses [6].

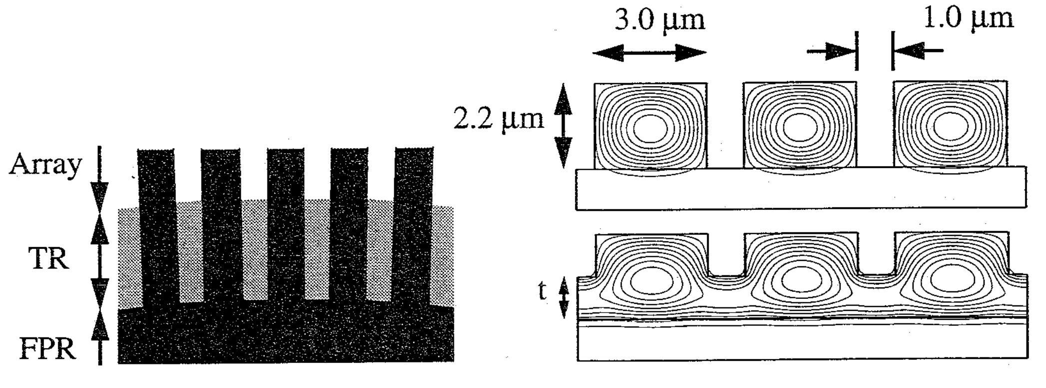


**Figure 3.** Detail of the transition region (TR) at the junction between the array waveguides and the free propagation region (FPR) (left, topview). Also shown are the field distributions in the waveguide structure as used for the array waveguides (upper right) and for the waveguides in the transition region (lower right).

Now the coupling between the FPR and the array waveguides takes place in two steps. First the fields in the array waveguides couple to the fields of the TR waveguides, and then these fields couple to the dominant order in the FPR. By increasing the thickness t of the TR, the efficiency of the latter coupling increases due to the fact that the exponential tails of the fields in the TR waveguides extend further into the film next to the waveguides, resulting in filling the zeroes between the individual waveguide modes. This TR thickness dependency of the coupling efficiency is shown in figure 4a (dashed line), where coupling losses for two slab-array junctions - at input and output aperture - are shown (only for TE polarisation). However, the coupling efficiency of the elliptical waveguide fields in the TR to the circular waveguide fields in the deeply etched array waveguides decreases with increasing TR thickness t (figure 4a, dotted line), and an optimum in the combined coupling efficiency can be found (figure 4a, solid line). The total coupling efficiency for t = 0 μm, i.e. without TR, is 3.5 dB. A similar graph can be obtained for TM polarisation. In figure 4b the total loss reduction is shown for both TE and TM polarisation. The optimum TR thickness is 1.1 μm, resulting in a predicted loss reduction of 2.2 dB for TE polarisation, and 1.9 dB for TM polarisation..

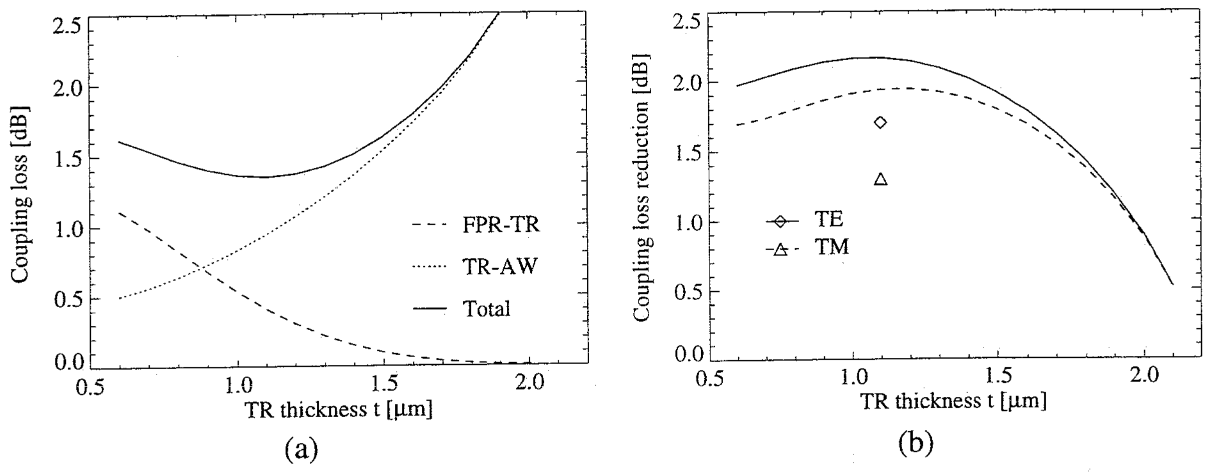


**Figure 4.** Coupling losses versus TR film thickness. In (a) the losses are shown for two slab-array junctions for TE polarisation: the dashed line depicts the coupling between the FPR and the TR, and the dotted line the coupling between the TR and array waveguides (AR). The solid line shows the combined loss. In (b) the total predicted loss reduction is shown for TE polarisation (solid line) and TM polarisation (dashed line). Also shown is the measured reduction for TE (diamond) and TM polarisation (triangle).

## Fabrication

Two phased-array demultiplexers have been fabricated using raised strip waveguides in LP-OMVPE grown undoped InGaAsP($\lambda_g$ = 1.02 μm) on InP substrate, one of which was used for the double etch experiment. The devices have 8 wavelength channels with a 2 nm channel spacing. The width and thickness of the raised strip waveguides are chosen as 3.0 μm and 2.2 μm respectively, to obtain zero birefringence. The etch depth for the TR was chosen 1.1 μm, yielding an optimum TR thickness of 1.1 μm. The length of the TR was chosen 10 μm, which is - according to BPM analysis - sufficiently short to get rid of the radiation modes excited at the first junction. The waveguides are reactive ion etched (RIE) using $Cl_2$ for smooth sidewalls and low scattering losses, resulting in an optical loss of 2 dB/cm both for TE and TM polarisation. Due to the high lateral index contrast, small bending radii can be used (200 to 500 μm), giving an array size of 1.0x1.3 mm$^2$, measured from object plane to image plane, and an overall device size of 1.2x3.3 mm$^2$ because the input and output waveguides are positioned with a 250 μm pitch for tapered fibre ribbon coupling.

## Experiments

Figure 4b shows the experimental improvement obtained. It can be seen that the reduction of the insertion loss is 1.7 dB for TE polarisation and 1.3 dB for TM polarisation, which is only

0.6 dB less than predicted. The gap between the waveguides was larger than in a previous design [5], which resulted in a slightly higher on-chip loss of 6 and 7 dB for TE and TM polarisation respectively, for the device with the transition region. Crosstalk values are -25 dB or better.

## Conclusion

We have demonstrated a method to reduce the insertion loss of phased-array demultiplexers. In this method an intermediate section with a shallow etch depth is inserted at the junction between the free propagation region and the array waveguides, resulting in lower coupling losses. Feasibility of the concept is demonstrated experimentally for an 8 channel demultiplexer with 2 nm channel spacing employing non-birefringent InGaAsP($\lambda_g$ = 1.02 μm)-on-InP raised strip waveguides. The measured on-chip loss is 7.7 and 8.3 dB for TE and TM polarisation respectively, for the device without the transition region. The device with transition regions showed an on-chip loss of 6 and 7 dB, resulting in a reduction of 1.7 dB and 1.3 dB for TE and TM polarisation respectively. This is only 0.6 dB less than predicted by theory.

## Acknowledgement

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