16 channels optical interface utilizing InP-based mode adapters combined with 30 µm intervals spaced fibre pitch converters

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The performance of an optical connection is determined between 16 single mode fibres and an InP-based chip. The optical interface consists of a fibre pitch converter in combination with on-chip spot-size converters. All optical transitions are uniform spaced at 30 µm intervals. The coupling efficiencies are 3 dB / channel and the 1-dB alignment tolerances are 1.2 µm for both linear lateral x- and transversal y-translations. The rotational 1-dB tolerance for the θ_z *roll position is ± 0.3°, measured at the outermost points of the fibres in the optical bus.*

Introduction

The high refractive index contrast between InP-based waveguides and cleaved single-mode fibres result in optical coupling losses of 10 dB for each optical connection. Therefore mode-shape matching is necessary to reduce the optical losses due to mode mismatch of the small elliptical widely divergent field of the waveguide compared to the ten times larger circular field of a single mode fibre with a narrow angle of acceptance. In this paper, the mode-shape matching is accomplished by spot-size converters (SSC's) [1] in combination with a fibre spacing concentrator (FSC). Hence, practical issues are described as well as the optical performance of the coupling method. Subsequently, the results are compared and discussed with the coupling approach of lensed fibre arrays.

Optical coupling system

The "standard" fibre pitch spacing of 250 µm is converted to 30 µm intervals by means of a commercially available FSC, which end facet is polished at an angle of 8° from top to bottom in order to reduce optical reflections. The measured mode field diameter (MFD) of the waveguides at the end facet is 9.5 µm with a numerical aperture of 0.1 at the 5% intensity level. The insertion loss of the FSC is 0.4 ± 0.1 dB / channel and the dimensions are 45 mm (l) x 6.5 mm (w) x 3 mm (h). The FSC is shown in figure 1, while the on-chip SSC is sketched in figure 2. The most critical component of the SSC is the 1.5 mm long vertical taper, which is used to adiabatically couple the light from the 600 nm primary guiding layer to a 5 µm secondary guiding layer underneath. More details about the SSC can be read in reference [1]. The optical mode is expanded from the regular 3 µm device waveguide (MDF of 2.7 µm x 0.9 µm) to the 6 µm wide waveguide (MDF of 6.5 µm x 5.8 µm). Owing to this increase in mode size, the loss due to mode mismatch from the SSC to a single mode fibre is reduced from 10 dB to 0.9 dB.

Alignment procedure

In contrast with lensed fibre arrays, aligning the FSC is more complicated due to the following reasons: first the positions of the waveguides of the FSC must be localised for the coarse aligning in the lateral x-direction. Next, as a consequence of the polished end

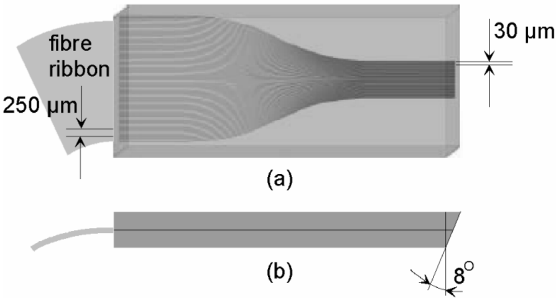

Fig.1 (a) Top view FSC, 16 fibers with 250 µm interval spacing are converted to 30 µm spaced intervals. (b) Side view FSC, the end facet is polished at an angle of 8°.

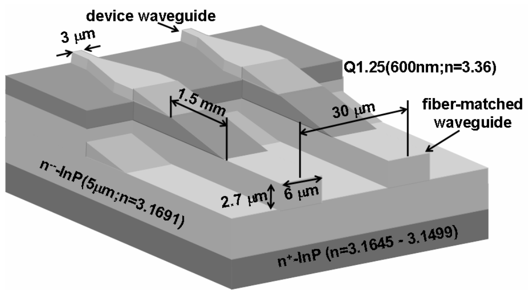

Fig. 2 Schematic representation of the SSC's (not to scale).

facet (see figure 1(b)) is the distance between the chip facet and FSC can not be visualized. This limited view makes the aligning in the transversal y-direction, just as the rotational θy-yaw alignment more difficult. Furthermore, the small air gab between the FSC and chip facet results in an interference phenomenon with an oscillating optical power fluctuation in the order of 1 – 1.5 dB. To perform the alignment, the FSC is mounted on a 6-axis piezo-electric controlled manipulator and positioned in front of an InP-based optical chip. The chip is a compact InP-based True Time Delay beam former with integrated SSC's [1]. A section of the chip is provided with a looped waveguides structure purposed for the investigation of the optical coupling performance. The section of the waveguide structure is shown in figure 3 (b). On the left-side are the SSC's, spaced at 30 µm intervals. The outer four looped waveguides are single looped waveguides, whereas the four inner looped waveguides are connected two by two through a 50/50 splitting ratio multimode interference (MMI) coupler. The positions of the waveguides of the FSC are observed with a microscope from the topside by illumination the FSC at the underside. A capture of the microscope view is given in figure 3 (a). The numbers 1 to 16 denotes the in- and output fibre connections of the FSC. Fibres 1 to 8 are connected to optical power meters, while fibres 9 to 16 are connected to an optical source. The height position of the FSC waveguides can be localised at both side views of the FSC. Namely, the waveguides are sandwiched between a top cover and substrate, both made from glass. A photograph is shown in figure 4. After the coarse visible alignment in the lateral x-, transversal y- and longitudinal z-direction, the FSC is fine positioned using active alignment of the outer waveguide loop. Due to the interference phenomenon which is related to the thickness of the air gab between the SSC and FSC, a broadband source is used. A typical plot is shown in figure 5. After physical contact between the FSC and chip facet at distance 0, the FSC is adjusted back until the first maximum power of the oscillating phenomenon is registered. This position is sketched with the mark (P) in figure 5. The position (P) is stable with the used broadband source. By using sources with longer coherence lengths, point (P) became instable. To determine the optimum roll θ_z position, the FSC is varied in the rotational θ_z direction. The relation between the θ_z roll position of the FSC and the chip facet is shown in figure 6. In this graph the two outermost fibre pair combination is observed, namely fibre 1 and fibre 16. The alignment tolerances for the 1-dB level are ± 0.3°. The FSC is aligned at an angle θ_z roll position of 0° and varied in the θ_x pitch direction. As a result of the polished end facet of 8°, the light is deviated from the optical z-axis. The dependence of the angular variation is shown in figure 7. If the FSC

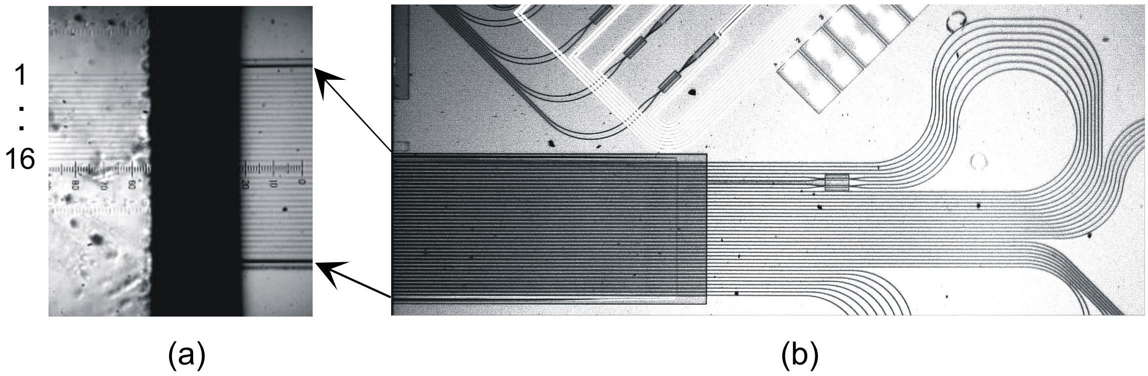

Fig. 3 (a) View of a microscope used for the coarse aligning in the lateral x-direction. The black colored area between the optical chip facet (right) and the FSC (left) is the shadow of the FSC as a consequence of the polished end facet of the FSC. The right photograph (b) shows the top view of the optical chip with looped waveguides combined with SSC's. The inner four waveguide loops are connected two by two through a 50/50 splitting ratio multimode interference (MMI) coupler.

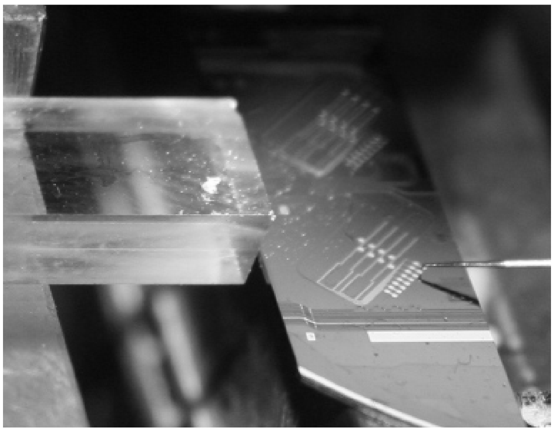

Fig. 4 Side view of the FSC and chip facet used for passive coarse alignment in the transversal y-direction.

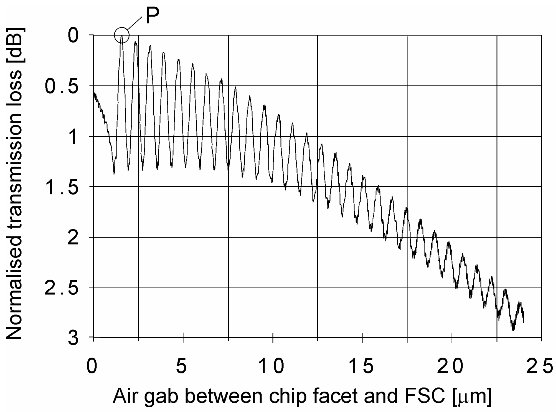

Fig. 5 Oscillating interference phenomenon because of the air gab between the FSC and chip fact. All measurements are registered at point P.

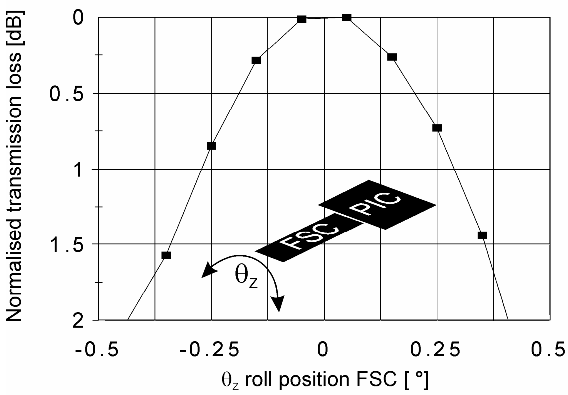

Fig. 6 Normalised additional transmission loss increment as a function of the rotational roll position of the FSC compared with the chip facet.

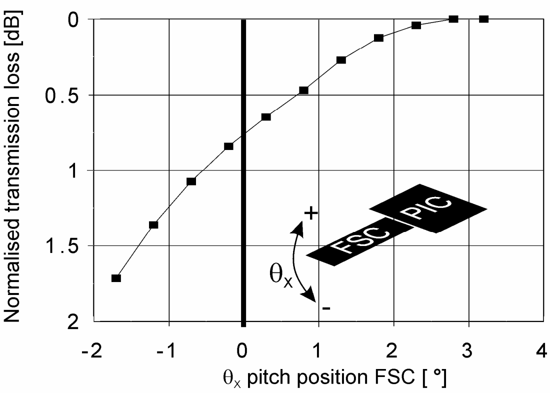

Fig. 7 Normalised optical coupling loss transmission as function of the pitch position between the FSC and chip facet

is rotated 3° with respect to the longitudinal z-alignment, the coupling efficiency is improved with 0.75 dB. The FSC is adjusted back at the 0° pitch position and the coupling efficiencies are determined for all 16 optical connections simultaneously.

Results

The FSC is linear translated from the optimum alignment in the lateral x- and transversal y-direction meanwhile all 8 optical transmission circuits are measured. The relative power loss increment as function of linear shift in x- and y-direction is plotted in figure 8 and figure 9, respectively. These figures show excellent channel spacing uniformity between the waveguide pitches of the FSC and SSC's. The transmission losses of all channels are listed in the last row of table 1, showing a transmission loss of 11.6 ± 0.4 dB / transmission circuit. These losses are composed as follows; 0.9 dB/cm shallow-waveguide propagation, 1.5 – 2 dB internal losses of the SSC, mode mismatch between the SSC and FSC is 0.9 dB / channel, insertion loss FSC is 0.4 dB / channel and 0.8 dB for the MMI coupler. An antireflection (AR) coating was not applied to the chip facet, so the remaining losses of 2.5 – 3 dB are introduced by the internal reflection losses of the chip facets.

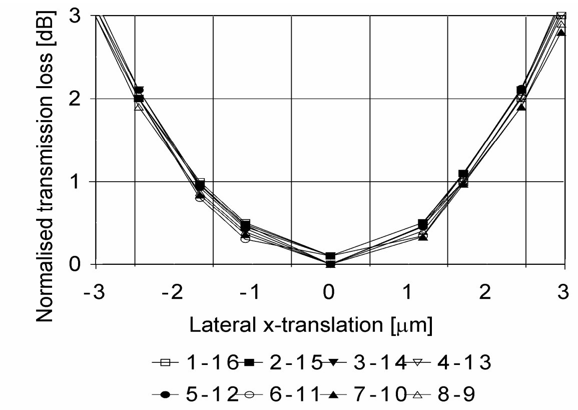

Fig. 8. Additional loss increment as function of lateral x-displacement.

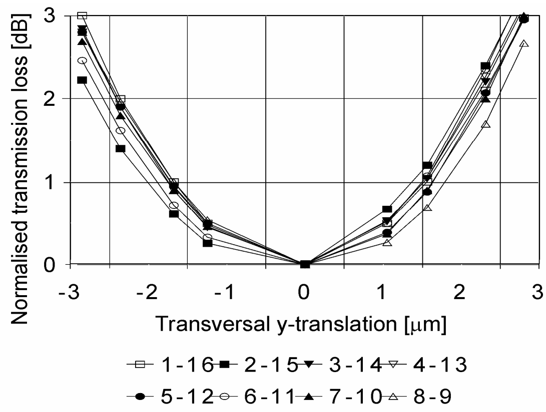

Fig. 9. Additional loss increment as function of transversal y-displacement.

Fibre pair [-]	1-16	2-15	3-14	4-13	5-12	6-12	5-11	6-11	7-10	8-10	7-9	8-9
Loss [dB]					17.0	16.3	14.6	14.1	14.9	14.2	13.7	14.6
Total loss [dB]	11.7	11.8	12.3	11.5	13.6		11.3		11.5		11.1	

Table 1. Measured coupling loss of the fibre pair combinations. The values of the middle row are measured after both MMI branches, whereas the last row shows the total transmission losses of all fibre pair combinations.

Discussion

The coupling efficiency of the waveguide-SSC-FSC-fibre system is determined to be -3 ± 0.3 dB / channel. For this 16 channel coupling system, the 1-dB alignment tolerances are 1.2 μm for both lateral x- and transversal y-translations and ± 0.3° for the θ_z rotational position. The coupling interface shows excellent channel spacing uniformity. In contrast, the inaccuracy of commercially available lensed fibre arrays are in the order of 1 – 2 μm, resulting in a coupling efficiency of -6.5 dB measured for eight fibres simultaneously in combination with waveguides without SSC's [2]. In conclusion, this coupling approach has the potential of increasing the number of fibre-chip connections. The interference effects can be reduced by applying an AR-coating on the chip facet and using an index matching material between the FSC and SSC's.

References

[1] F.M. Soares et al in Proc. IPRA Conference USA, paper IMF5, 24-26 April 2006.

[2] J.H.C. van Zantvoort et al IEEE/JSTQE Sept/Okt 2006.