Multi-Fibre to InP-based Waveguides Coupling Efficiency Determination

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The feasibility to couple light simultaneously into standard InP based waveguides using up to 8 single mode fibres is investigated with a commercially available fibre-array. The practical maximum coupling efficiency and the dependence of coupling efficiency as a function of lateral and transversal misalignment is measured and compared for both standard 3 μm and tapered 6 μm width waveguides.

Introduction

Optical devices based on InP technology can be made compact due to the high refractive index of this material and active components can be integrated. Disadvantage is a high coupling loss between the smaller monomode waveguide and a single mode fibre. To reduce those losses, lensed fibres can be used. Devices like optical cross-connects and add-drop multiplexers require multiple fibre chip connections, therefore several fibre coupling experiments were carried out employing commercially available fibre-array's.

Experimental set-up

The 8 fibre-array can positioned in two linear x and y axes and in one rotational about the z axis. Opposite to the fibre-array, a stage can moved in the other three degrees of freedom: linear in the z direction and rotational about the x and y axes. A second fibre-array or an optical chip can be mounted on this stage. Behind the stage a single lensed fibre can be adjusted in the x, y and z axes.

IR spot positions measurements of the 8 fibre-array

The IR spot positions of a fibre-array depend on the fibre pitch and the lens eccentricity of the individually lensed fibres. A deviation in the fibre pitch of the third fibre of the 8 fibre array was visible using a microscope. To measure the deviation of IR spot positions due to the lens eccentricity, another array of four fibres is used. The first four fibres of the 8 fibre-array are connected with a laser source by a 1:4 splitter and the 4 fibre-array is connected with power meters. If the maximum power is measured from a certain fibre to fibre coupling, the x, y and z piezo coordinates is a measure for the IR spot position. The concerned fibres of both array's determine the spot position, so the 8 fibre-array is aligned to the 4 fibre-array in 6 different positions. Each position has an offset of 250 μm. If all offsets of 250 μm are eliminated from these 6 observations the tendency of absolute IR spot position of the first four fibres 1,2,3 and 4 of the 8 fibre-array is measured in x, y and z direction. These measurements are repeated for fibres 2,3,4,5; 3,4,5,6; 4,5,6,7 and 5,6,7,8. In figures 1 and 2 are given the x and y position, when the maximum transmission occurs. From the first plot, it is obvious that the IR spot position between fibres 2,3 and 4 differ. In all configurations fibre 3 of the array must be shifted 2 μm by comparisation with fibre 2. The IR spot position between fibre

2 and 3 is about 252 μm and the IR spot position between fibre 3 and 4 is less than 250 μm. The second plot shows the difference in IR spots in the transversal y-direction. Extremes are fibres 3, 6 and 8 and in opposite direction fibre 4 and 7. In the z direction (distance between fibre-tips) no worth mentioning observation was done. During these experiments the losses due to mode field mismatch of the opposite fibres and losses of the fibre connectors are measured and the results are plotted in figure 3. The average system loss is 1 dB. To check these results the transmission is measured using a single fibre with a lens radius of exactly 14 μm. The same trend is observed and the average measure points are connected with a line in figure 3.

Fibre waveguide coupling loss measurements

In figure 4 the optical chip layout and the used numbering of the waveguides and fibre-array is given. There are 12 straight waveguides (w1 till w12) and 6 waveguide loops of 7 waveguides (L1 till L6). The waveguide pitch is 125 μm. The dimensions of the straight waveguides and waveguide loops L1 till L4 are standard 3 μm x 0.6 μm. Two waveguide loops L5 and L6 have tapered waveguides in the lateral dimension of 6 μm. Calculations demonstrated the same coupling efficiency with lensed fibres of 14 μm and some relaxation of the fibre alignment in lateral direction is desirable. IR light is coupled in the straight waveguide with the fibre-array and on the opposite side, light is couple out the chip using a lensed fibre with a lens radius of exactly 14 μm. On each waveguide 8 observations were done using the fibre-array. Total there are ± 100 measurements. The results are plotted in figure 5 and they are corrected for the waveguide loss (± 1.4 dB) and system loss (fig 3). The average loss of two fibre-chip couplings (in- and output) is 8.8 ± 0.8 dB. Fibre 5 of the fibre-array has 2 dB additional more losses.

Waveguide loops coupling measurements

Initial the two fibres outside of the used fibres in each experiment are alignment at maximum transmission. In this position, the transmissions of the other fibre pairs are measured. After this, the maximum transmissions of the inner fibre pairs are measured by adjusting the x, y and z piezo controllers. This measurement is repeated 8 times by shifting the fibre-array 4 times 125 μm left and right compared with the waveguides from the initial position. For each waveguide loop (L1 till L6) are 9 measurements: 1 observation with 4 fibre pairs, 4 observations with 3 fibre pairs and 4 observations with 2 fibre pairs. Note that the fibre-pair combinations changes 24 times in composition in these 9 measurements and total there are ± 50 observations whereby the transmission is measured from the inner fibre-pair(s) if the two outer fibres are aligned at maximum transmission. The first 2 measurements of each waveguide loop are plot in figure 6. The two thick black lines in figure 6 shows the trend in total excess loss if fibre-pairs 1-8 (in1-out14), 2-7 (in3-out12), 3-6 (in5-out10), 4-5 (in7-out8) and fibre-pairs 1-7 (in2-out13), 2-6 (in4-out11) and 3-5 (in6-out9) are used. The excess losses of the fibre-pairs are about 12 dB, 20 dB, 16 dB, and 24 dB. If 3 or 2 fibre-pairs are used excess loss of 12 dB till 16 dB were measured. The average excess loss of all optimum observations (4 x 24 measurements) for waveguide loops L1 till L4 is 13.4 ± 1.4. For waveguide loops L5 and L6, which have tapered waveguide ends 1 dB more excess loss is observed in 2 x 24 measurements: -14.4 ± 1.8 dB. If we assume that the average on chip loss is 1.5 dB and the system loss is 2 dB (2 times a fibre with connection of the 8 fibre array in figure 3), the average coupling loss of two fibres simultaneously is about 10 dB. In figure 7 is given re-adjusting in the transversal x-position as a function of the maximum transmission of each individual fibre-pair from the initial position in figure 6. If fibre-pair 3-6 (in5-out10) or fibre-pair 3-5 (in6-out9) is adjusted at maximum transmission, the fibre-array must be adjusted ± 1 μm in positive lateral x-direction and fibre-pair 4-5 (in7-out8) must be adjusted in opposite direction. This phenomenon is observed for all other 7 experiments; if fibre 3 is one of the two fibre-pair combination, the array must always re-align in positive lateral x-direction. The array must be re-align in opposite direction if fibre 4 is one of the fibre-pair combination. This corresponds to the first observations of the IR spot positions measurement of the fibre array (figure 1). Figure 8 shows re-adjusting in the transversal y-direction. Fibre-pairs 2-7 (in3-out12) and 4-5 (in7-out8) must be re-aligning a distance of about 1-1.5 μm in comparisation with with the other fibre-pairs 1-8 (in1-out14), and 3-6 (in5-out10). The fibre-array must re-align to the upper surface of the chip if fibre-pairs combinations with fibre 4 and fibre 7 are used and the array must be re-align downwards if fibres 6 and 8 are one of the combinations. These observations are consistent with the results measured in figure 2.

Coupling efficiency as a function of misalignment measurements

To investigate the increase of excess loss as a function of misalignment observations were done using straight waveguides and single fibres. In figure 9 and 10 normalised curves are given for displacement of the fibre in lateral and transversal direction. For both directions, a shift of 1.5 μm of a single fibre in front of a standard 3 μm x 0.6 μm waveguide caused an extra excess loss of 3 dB. From two waveguide loops L4 and L6 with standard 3 μm and tapered 6 μm width waveguides, 24 observations each were done. All observations show an equal tendency. Typical curves are also plot in figures 9 and 10. In lateral direction the –3 dB level occur at about 1 μm for the 3 μm and 1.4 μm for the 6 μm width waveguide structure. In transversal direction an extra loss of 3 dB occurs at a misalignment of less than 1 μm. Actually, the curves in lateral direction for 3 μm width waveguides and all curves in transversal direction must be the same, but this was not observed due to the quality of the fibre-array.

Conclusions

A deviation of ± 2 μm of the focussed IR spots in lateral and transversal direction is measured at a commercially available 8 fibre-array. The minimum practical coupling loss between two independently controlled lensed fibres with a lensradius of 14 μm and standard waveguides is 8.8 ± 0.8 dB. This corresponds with the theoretical gaussian beam approximation calculation (4.5 dB for one fibre waveguide transion). The average minimum coupling loss with 2 fibres simultaneously is about 1 dB higher. Average coupling losses of about 10, 18, 14 and 22 dB were measured with 4 fibre-pairs simultaneously, losses of 10 till 14 dB were measure for 3 and 2 fibre-pairs. The increase of excess loss of two fibres simultaneously is about 3 dB for 1 μm misalignment in transversal direction and 1.5 μm misalignment in lateral direction. If the waveguides are tapered from 3 μm to 6 μm, the tolerance of misalignment of the fibre hardly increases and the measure coupling losses are in general 1 dB higher than the standard 3 μm waveguides.

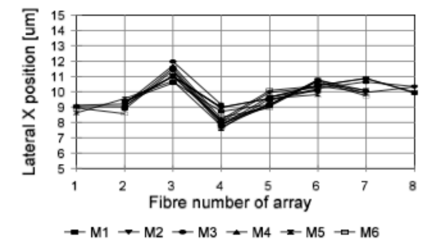

Fig.1 Relation IR spot position lateral direction

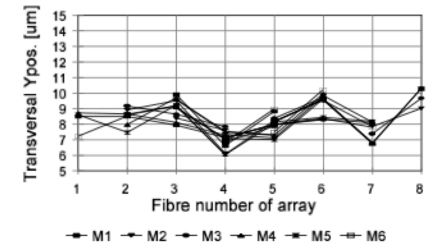

Fig.2 Relation IR spot position transversal direction

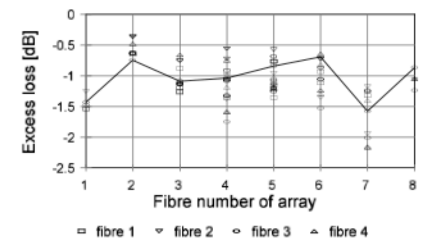

Fig.3 8 fibre to 4 fibre coupling measurements

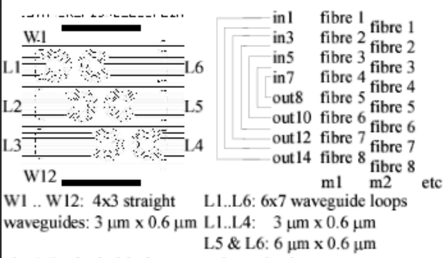

Fig.4 Optical chip layout and numbering

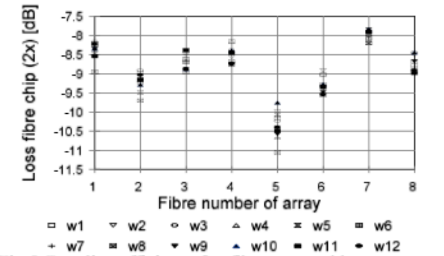

Fig.5 Coupling efficiency 2 x fibre waveguide

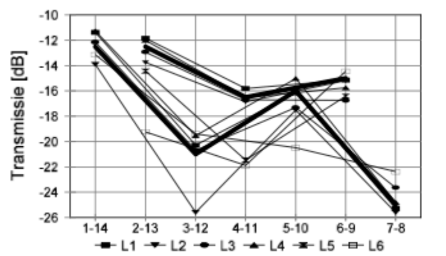

Fig.6 Excess loss first 2 measurements of each loop

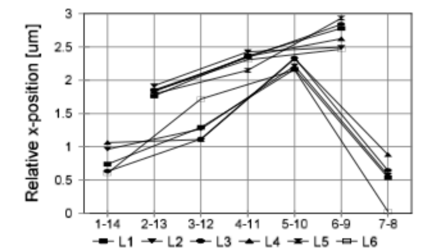

Fig.7 Lateral re-adjusting for maximal transmission

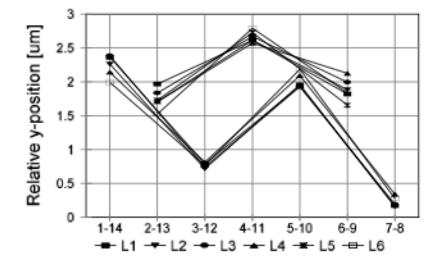

Fig.8 Transversal re-adjusting for maximal transmission

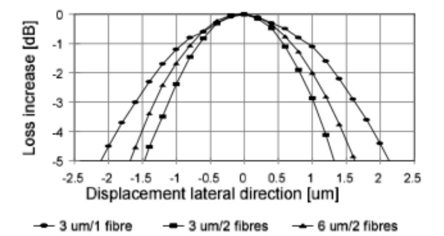

Fig.9 Normalised curves lateral displacement fibres

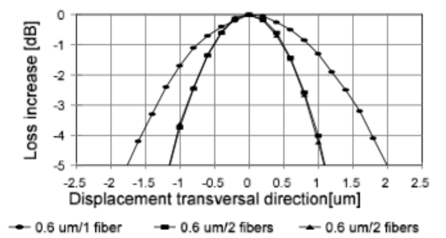

Fig.10 Curves transversal displacement fibres