

# Fibre-Array to Photonic Chip Fixation and Re-alignment using Laser weld Adjustment

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*A new concept for coupling fibre arrays to an optical chip in the sub-micron range is presented. The possibility for re-alignment after permanent fixation has been demonstrated. The smallest re-alignment step of 0.1  $\mu\text{m}$  is measured using laser adjustment. To investigate the mechanical stability, a fibre array and chip with wave-guide loops will be used. For this experiment, the infrared spot distribution of a commercially lensed four fibre array is measured. The accuracy of the infrared spot determination is better than 0.4  $\mu\text{m}$ . These results are compared with the coupling efficiency of the fibre-tips in combination with standard InP-based wave-guide loops.*

## Introduction

The absolute position of optical in- and output wave-guides on photonic integrated circuits (PICs) can be made very accurately by using lithographical processes. The problems arise as soon as multiple fibres must be connected to InP-based wave-guides. Mode matching is necessary to reduce losses in mode mismatch between single mode fibres and mono mode wave-guides. Lensed fibre arrays can be used, but due to the technology nowadays the deviation of the infra red (I.R) spot from a standard pitch of 250  $\mu\text{m}$  is in the order of 1-3  $\mu\text{m}$ . This is caused by the lens eccentricity of each individual fibre tip, a typical specification is smaller than 1.5 - 2  $\mu\text{m}$ , spacing in the V-grooves of  $250 \pm 0.25 \mu\text{m}$  and assembly method in the V-groove chip where most frequently adhesives are used. In this paper we describe a method to connect fibre array to PICs, the determining of IR spot distribution of commercially fibre arrays and the optimum coupling efficiency as a function of lateral, transversal and axial alignment.

## Pigtailing method

Pigtailing encompasses the alignment optimization and attachment of optical fibres to PICs. The new pigtailling concept consists of the next procedure:

- Fixation of the optimum distance between lensed fibre tips and chip facet.
- Alignment of the fibre array in lateral, transversal and axial positions using piezo-electric actuators.
- Fixation of the fibre array using laser welding in combination with a smart frame.
- Removing piezo-electric actuators and re-aligning of the fibre array using laser adjusting of the smart frames.

In figure 1 the design is given. The chip will be fixed on part (1). The fibre array is mounted on part (2). Both components must visually aligned adjusting the in- and output wave-guides to be parallel and opposite of the fibre tips. At this stadium both components will be fixed with adhesive. The optimum distance between fibre tips and PIC can be achieved by adjusting part 2 parallel towards the PIC facet in the linear z direction. This part is mounted on two sliding bars at part 3 and held in position by a spring. Permanent fixation of this part to the sliding bars is done by filling the 4 holes with low shrinkage epoxy. The influence of the shrinkage effect in the z-direction of the

epoxy during curing is minimized as the forces in this direction are avoided as a consequence of the perpendicular direction of the holes to the rod. Part 2 and 3 together can be aligned in lateral x, transversal y and in the  $\theta_z$  roll direction by means of 3 elastic pins (4). Alignment is performed using 3 external piezo-electric actuators, which are connected temporary to part 3.

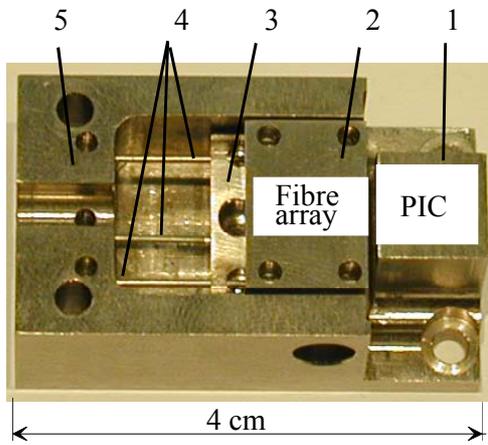


Fig.1 Fibre array PIC coupling construction

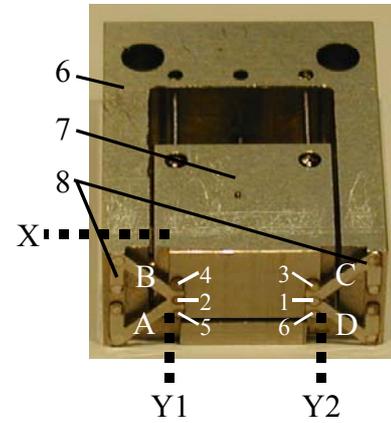
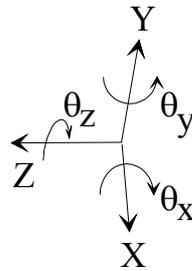


Fig 2 Prototype laser weld fixation

After optimum alignment of the flexible part combination 2 and 3, the fibre array must be fixed to rigid part 5. In figure 2 a prototype of the fixation construction is given. Part 7 is laser welded to part 6 with the help of 2 smart frames (8). These frames are already laser welded to part 6. Part 7 is connected to 3 displacement transducers X, Y1 and Y2 and the following sequence of welding is done: 1, 2, 3, 4, 5 and 6. Due to the post-weld-shift (PWS), part 7 is shifted  $-3.2 \mu\text{m}$  in the lateral x direction. In the transversal y direction, transducer Y1 indicated a shift of  $3.7 \mu\text{m}$  compared to the initial situation. Transducer Y2 measures a shift of  $-2.6 \mu\text{m}$ . With the design of the smart frames laser adjustment is possible by welding the plates at position A, B, C and D. By laser induced local heating the smart plates will shrink, which causes the adjustment of part 7. To re-adjust part 7 to the initial position, position A is welded 5 times. This results in  $X=-1.2 \mu\text{m}$ ,  $Y1=0.4 \mu\text{m}$  and  $Y2=2.4 \mu\text{m}$ . So the x direction and Y1 position are re-adjusted. Part 7 is re-adjusted further to the initial position by welding 1 x B, 2 x A, 3 x D, 3 x B, 1 x A, and 1 x C respectively. The smallest measured displacement is  $0.1 \mu\text{m}$  at minimum pulse energy of the laser welder. To reduce the PWS, the Nd:Yag laser welder will be expanded from one to two focusing heads, so both smart frames will be welded simultaneously with the same energy. To investigate the mechanical stability the pigtailing method will be tested by coupling a lensed 4 fibre array to an InP-based PIC with wave-guide loops [1].

### Fibre array infra red spot position determination

The I.R. spot position formed by the lensed fibres of fibre array can be measured with a lensed fibre, which is connected to a power meter. If the fibres are launched with a laser source, the maximum measured power corresponds with the position of the I.R. spot. In the set-up, the fibre array is mounted on a 6-axis flexure stage, and the lensed reference fibre with a lens eccentricity of  $0.18 \pm 0.08 \mu\text{m}$  [2] is mounted on a 3-axis piezo controlled stage with active feedback. This stage is mounted on a translation stage with a linear encoder. The system is automatically controlled by a personal computer for the

translation of exact 250.0  $\mu\text{m}$ . Using an interference measurement rapport of the translation stage the best position regarding flatness, straightness, tilt and wobble is chosen. I.R. spot measurements were performed at 29 different positions side by side of the stage. Each position has an offset of 250.0  $\mu\text{m}$  compared to the previous position. The absolute I.R. spot positions and the population standard deviation of all observations in lateral x and transversal y direction are given in figures 3 and 4.

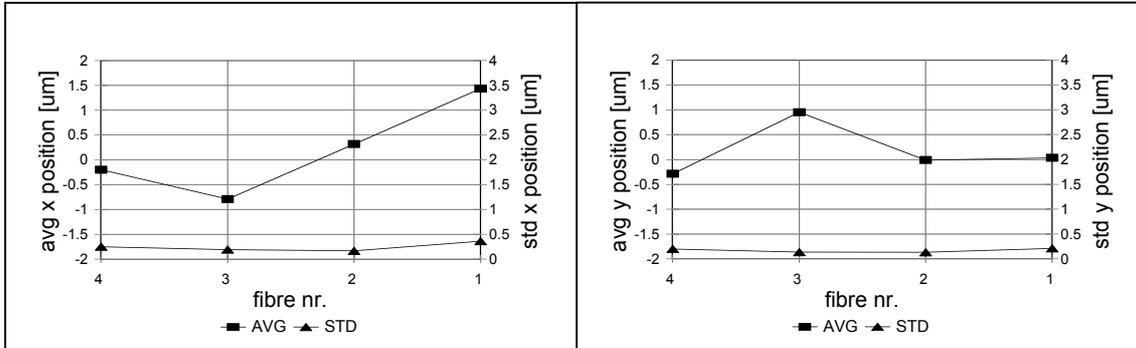


Fig 3 I.R spot position lateral x direction      Fig 4 I.R spot position y direction

From figure 3 can be concluded that the I.R. spot pitch between fibres 1 and 2 is  $249.9 \pm 0.6 \mu\text{m}$ , between fibres 2 and 3, the I.R. spot pitch is  $248.9 \pm 0.4 \mu\text{m}$  and between fibres 3 and 4 the I.R. spot pitch is  $250.6 \pm 0.5 \mu\text{m}$ . Fibres 1 and 4 will be connected to a wave-guide loop and fibres 2 and 3 will be connected. The pitches between those two fibre pairs 1-4 and 2-3 are  $748.4 \pm 0.7 \mu\text{m}$  and  $248.9 \pm 0.4 \mu\text{m}$  respectively. In figure 4 can be seen that the I.R. spot of fibre 3 has a deviation of 1  $\mu\text{m}$  in the transversal y direction.

### Fibre array wave guide loop experiments

With the fibre array, characterized in the previous section, a number of wave-guide loop experiments were carried out. Fibres 1 and 2 of the array are connected to a laser source, fibres 3 and 4 are connected to power meters. First the optimization in lateral x, transversal y and roll position  $\theta_z$  is determined. After this, angular dependence in the coupling efficiency in the pitch  $\theta_x$ , and yaw  $\theta_y$  of the fibre array in relation to the chip facet is investigated. To find the optimum position of the fibre array, fibre pair 1-4 is optimally aligned. The transmission curve is measured when the fibre array is translated 4  $\mu\text{m}$  in both lateral and transversal direction. The same procedure is done for fibre pair 2-3. This measurement is done for different  $\theta_z$  roll positions. In figure 5 and 6 the optimum transmission as a function of the roll position is given. There are 2 optimum positions for both fibre pairs, but regarding mechanical stability, the optimum of fig 6 if fibre pair 2-3 is optimally aligned is preferred. The total excess loss for both fibre pairs is 13.5 dB. This is composed of two times the coupling loss as a result of mode mismatch between wave-guide dimensions and fibre tip with a radius of 14  $\mu\text{m}$ , which is equal to  $8.8 \pm 0.8 \text{ dB}$  [3]. Furthermore, extra loss in lateral misalignment due to the I.R. spot pitch of both fibre pairs which are  $748.4 \pm 0.7 \mu\text{m}$  and  $248.9 \pm 0.4 \mu\text{m}$  for fibre pairs 1-4 and 2-3 respectively. This loss is about 1.5 dB [3]. And extra losses are due to fibre 3 misalignment in the transversal direction: 1 dB [3]. Additionally, another 2 dB is due to wave-guide losses of 14 mm wave-guide length.

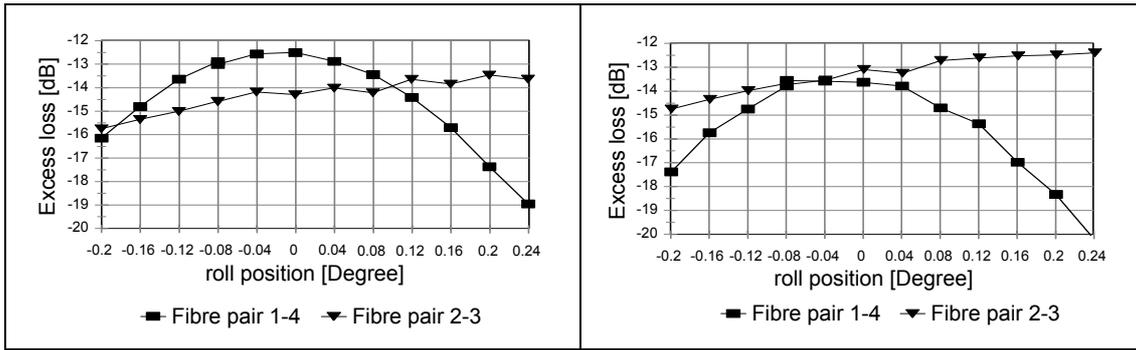


Fig 5 Coupling efficiency 1-4 optimized      Fig 6 Coupling efficiency 2-3 optimized

From all measurements it is observed that the optimum transmission of each fibre pair individually occurs with a lateral shift of  $0.2 \mu\text{m}$  and transversal shift of  $0.6 \mu\text{m}$ . This corresponds with the I.R. spot position determination. The array is set at a roll position of  $-0.04$  (fig 6), and the  $\theta_x$  pitch position of the array is varied over a range of  $6^\circ$  ( $3^\circ$  up and  $3^\circ$  down) compared to the chip. This has no influence on the coupling efficiency. The  $\theta_y$  yaw position is translated over a total angle of  $1.2^\circ$ . Here again  $0.6^\circ$  left and  $0.6^\circ$  right of the parallel position. This is also not crucial for the coupling efficiency. Coupling efficiency as a function of the fibre tips to chip facet distance is investigated. In all observations there was a difference of about  $5 \mu\text{m}$  in maximum coupling efficiency for both fibre pairs in the z-direction, this results in an extra loss of  $0.25 \text{ dB}$ .

## Conclusions

A prototype of the pigtailed concept is tested. Re-align using laser adjustment is demonstrated to compensate for the PWS. Re-alignment in the order of  $4 \mu\text{m}$  in lateral and transversal direction is measured after permanent laser weld fixation. The minimum re-alignment step is  $0.1 \mu\text{m}$  in both lateral and transversal direction. To test the final design, an InP-based PIC with standard monomode waveguide loops will be pigtailed. For this purpose the I.R. spot positions of a commercially 4 lensed fibre array is measured. I.R. fibre pair spot pitches of  $248.9 \pm 0.4 \mu\text{m}$  and  $748.4 \pm 0.7 \mu\text{m}$  are measured instead of  $250.0 \mu\text{m}$  and  $750.0 \mu\text{m}$ . In transversal direction one I.R. spot position is  $1.0 \pm 0.2 \mu\text{m}$  off axis located by comparison with the other 3 fibres. Due to this, 2 optimum lateral x, transversal y and  $\theta_z$  roll positions of the array are measured. Extra excess loss of  $2.7 \pm 0.8 \text{ dB}$  in both fibre pair combinations is introduced as a result of the quality of the commercially fibre array.

## References

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