Novel fibre array assembly technology

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This paper describes the utility of commercially available lensed fibre arrays in combination with standard mono-mode InP-based waveguides and the characterization of hemi-spherical lensed fibres with lens radii in the range of 5 µm – 15 µm. The alignment errors of commercial fibre-arrays are in the order of 1 µm – 2 µm. In combination with relatively large lens radii, the fibre-to-waveguide coupling efficiency is limited to –6.5 dB. A design is presented for a novel fibre-array assembling technology, which enables to reduce the alignment error, so fibres with small lens radii can be used to increase the coupling efficiency.

Introduction

Technological solutions for the alignment and reliable fixation of multiple fibres in order to improve the coupling efficiency are important for multiple port optical integrated circuits. The mean contribution of the coupling loss between single-mode fibre and waveguide is the mode miss-match of the small elliptical widely divergent field of the waveguide compared to the 10 times bigger circular field of the fibre with a narrow angle of acceptance. A second contribution is the lateral or transversal offset due to the core eccentricity of the individual fibre. In previous work [1] we have investigated the application of elliptically imaged lensed fibres, however, our conclusion is that these types of fibres are not applicable in combination with InP-based standard single-mode waveguides. In this work we investigated hemi-spherically lensed fibres with small lens radii up to 5 µm. To overcome the contribution of the core eccentricity, we demonstrated, in previous work, that if the eccentricity of each fibre is measured, fibres with similar eccentricity could be selected and mounted in a V-groove by rotating the fibres according to the direction of the eccentricity [2]. Another solution is using a partially-metal-coated fibre in a silicon V-groove. The core position can align by rotating the fibre [3]. In this paper we propose a design, whereby the fibres can be aligned individually.

Measurements on hemi-spherical fibre tips

For the selection of the most efficient fibre tips, coupling efficiencies between standard InP-based wave-guides and hemi-spherical lensed fibres have been measured for fibres with lens radii of 5 µm, 10 µm and 15 µm. The lensed fibre tips of 5 µm and 10 µm were manufactured with 2 different tapered angles of 50° and 90°. After the determination of the coupling efficiency, the displacements for a 1 dB coupling loss increment for the three linear displacements of the fibre in front of the waveguide have been measured. A complete hemi-spherical far field profile was measured using a 3D-scanning goniometric radiometer. From the far field data, the numerical aperture was determined at the 13.5 % ($1/e^2$) intensity level and the mode field diameter has been calculated. In table 1, the average results are given for 3 observations from each setup.

Lens radius [µm]	Tapered angle [°]	Fibre-waveguide coupling efficiency [dB]	Dx [µm]	Dy [µm]	Dz [µm]	NA at 13.5 % intensity level [-]	Mode field diameter [µm]
15	50	-4.4	± 0.8	± 0.7	± 4	0.24	3.6
10	50	-3.6	± 0.7	± 0.6	± 3	0.26	2.9
10	90	-3.6	± 0.7	± 0.6	± 3	0.32	2.8
5	50	-4.1	± 0.6	± 0.4	± 2	0.48	2.1
5	90	-2.8	± 0.6	± 0.4	± 2	0.57	2

Table 1 Measured result of hemi-spherical lensed fibres with radii of 15 µm, 10 µm and 5 µm

From left to right are given: the radius of the fibre tip, tapered angle of the fibre tip, the coupling efficiency between fibre and wave-guide, the displacement of the fibre tip for 1 dB extra power increment in lateral x direction, transversal y direction and longitudinal z direction, the measured numerical aperture of the fibre and the calculated mode field diameter of the fibre. If the lens radius decreases, the numerical aperture increases and the mode field diameter decreases. Therefore, the coupling efficiency increases because the mode matching is better compared with the small elliptical field and the widely diverging field of the waveguide. But if the radii decrease, the Fresnel loss increases rapidly due to light, which misses the lens or is internally reflected. [4]. In our case an anti-reflection coating for 1550 nm reduces this phenomenon. The back-reflections are measured and fibres with lens radii of 5 µm in combination with tapered angles of 50° show more reflections than the other fibre types. Fibre tips with radii of 5 µm and tapered angles of 90° give the minimum back-reflection and the best coupling efficiency of 2.8 dB average. The numerical apertures of fibres with tapered angles of 90° are higher than of those with tapered angles of 50°. In figure 1, photographs of both fibre tips with different tapered angles are given.

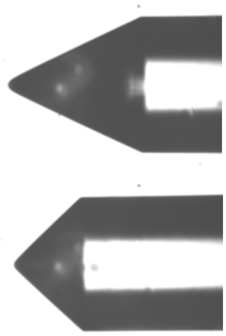

Fig.1 Lensed fibre tips with lens radii of 5 µm and tapered angles of 50° (top) and 90° (bottom).

Fibre array characterization

Measurements are carried out on two fibre-arrays, which are, to our knowledge, the best available lensed arrays with respect to the focused infrared (IR) spot distribution of the individual fibres. The two fibre arrays are assembled using 8 hemi-spherical lensed fibres with lens radii of 15 ± 0.5 µm. The IR spot position is measured and compared with the data of the manufacturer. The measurement principle is based on maximum light transmission between the concerned fibre of the fibre array and a reference fibre. The reference fibre can be adjusted in 3 dimensions with high accuracy and long travel. Repetitive results show a good agreement with the measured specifications of the manufacturer. The maximum deviation is ± 1 µm in lateral and transversal direction and about 6 µm in the longitudinal direction. In the next experiment both fibre arrays were connected to an InP-based optical chip with waveguide loops. Fibres 1 till 4 were connected with a splitter to laser source and fibres 5 till 8 were connected to 4 power meters. So fibres 1 and 8, 2 and 7, 3 and 6, and 4 and 5 form pairs by guiding the light from the input fibre trough the on chip waveguide loop, back to the output fibre. The transmission curves as a function of the displacement of the chip in lateral x direction and transversal y direction were measured for different roll θz positions of the fibre-array. The θz roll positions are measured in a range of 0.2º with intervals of 0.02º. From each roll position, first fibre pair 1-8 is optimized for maximal transmission and the transmission of fibre-pairs 2-7, 3-6 and 4-5 are measured. This procedure is also repeated for the other pairs. From all data, the optimal position of the fibre array compared with the chip can be determined. The fibre-array is set at the optimal position and the total transmissions of –14 dB and –15 dB are measured for all fibres simultaneously for both fibre arrays respectively. The estimated waveguide loss is 1.5 dB, so the loss of one fibre-to-waveguide coupling should be in the order of 6.5 dB. Compared with the measurements of table 1 it can be concluded that due to the pitch errors of the fibre arrays, extra losses of 2 dB are introduced for all 8 fibre chip transitions. Displacements of 0.5 µm in lateral x or transversal y directions of the fibre-array compared to the chip facet, result in 1 dB extra power loss of the fibre pair combination concerned.

Fibre array assembly technology

If it is possible to adjust and fix the fibres individually in an array, the eccentricity of the lens on the fibre tip can be eliminated and optimal multi-fibre-chip connection is possible with an efficiency of –3 dB by using fibres with radii of 5 µm and tapered angles of 90°. Laser-supported adjustment with the possibility of fine-tuning despite already secured positions between the parts due to precisely chosen step-by-step deformations in the construction is demonstrated for coupling fibre arrays to photonic chips [5]. Laser contraction is based on elastic and plastic material deformation [6]. When a piece of material (see figure 2, picture 1 schematic presented by part (a)) is clamped mechanical to a solid surrounding (represented by both black bars (b)) and it is partly welded by a laser beam over the whole cross-section of the material (picture 2), the heated zone expands elastically ((c), picture 2). When the temperature of the material is further increased, the material plastically deforms if the expansion of the material is obstructed (picture 3). After the heated part of the material is cooled down to room temperature, the shrinkage arises from the plastic deformation of the heated part (picture 4). In addition when this shrinkage is obstructed, tensile stress ((σ) schematically presented in picture 5) will be generated in the opposite direction to the applied force due to the plastic deformation of the material piece. In this condition expansion or shrinkage of the piece can occur, depending on the tensile stress in the material and the forces generated by the plastic deformations. This is experimentally verified, by measuring the displacement of a mechanical construction as a function of welded position, laser pulse duration and laser beam diameter of an Nd:Yag laser source. An adjustment range of 5 µm has been measured, while the smallest displacement step is 0.05 µm. These parameters are sufficient for the proposed application.

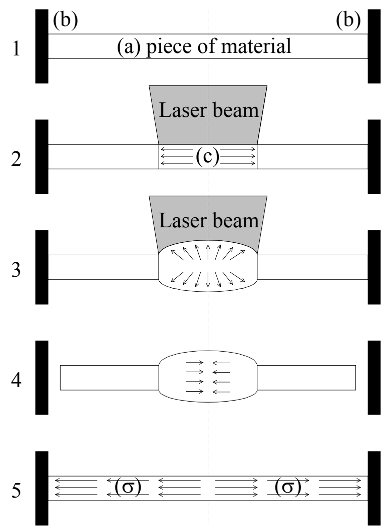

Fig. 2 Schematic presentations of laser support adjust mechanism.

In figure 3, an artist impression is given of the first designs. Fibres (1) are already mounted in a silicon V-groove substrate (2) and the fibre tips can be adjusted in the x-y plane perpendicular to the fibre tip using the adjust frame (3), in which the fibres are already fixed. If the adjust frame tends to bend during the laser adjustment process and causes mis-alignments in the z-direction, this design can be expanded to a 3D micro-metal assembly, whereby the fibres can also be adjusted in the longitudinal z direction. In figure 4, this design is given. The fibres are mounted in a support (4), that controls each fibre in the z direction independently by using the adjustment beams (5).

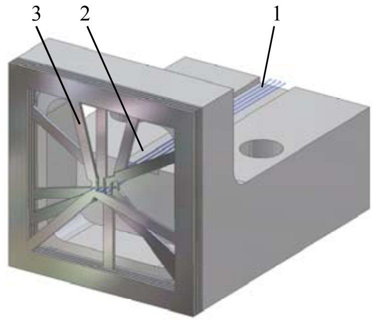

Fig. 3 Design for align fibres individually in x-y plane by using laser support adjustment

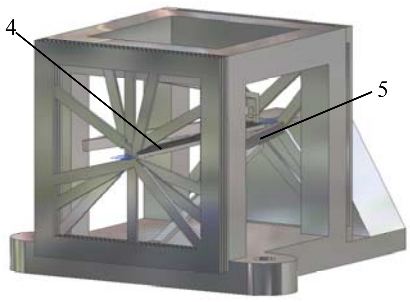

Fig. 4 Design for align fibres individually in x-y-z space by using laser support adjustment

Conclusions

The best measured coupling loss to a standard mono-mode waveguide is 2.8 dB for a fibre tip with a lens radius of 5 μm and a tapered angle of 90°.
The alignment errors of commercial fibre-arrays are in the order of 1 μm – 2 μm. The coupling losses of these devices are –6.5 dB for all fibres simultaneously. These losses are composed of 4.5 dB for the lensed fibre-to-waveguide transitions using lens radii of 15 μm, and of 2 dB due to the alignment error in combination with the lens eccentricities of the individual fibres of the fibre-array.
Fine-tuning of 0.05 μm displacement over a range of 5 μm of already secured parts has been demonstrated by laser welding-induced local heat

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