Coupling Efficiency Determination between Elliptically Imagined Spot-sized Fibres and standard InP-based Wave-guides

J.H.C. van Zantvoort, G.D. Khoe and H. de Waardt

COBRA Research Institute, Eindhoven University of Technology EH-12
P.O. BOX 513, 5600 MB, The Netherlands, E-mail: j.h.c.v.zantvoort@tue.nl

The coupling efficiency between two different manufactured types of commercially available chisel lensed fibres and standard mono-mode wave-guides on InP is determined. The shape of these fibre tips directs the light onto an elliptical spot. This should improve the coupling of light between the circular mode field of single mode fibres and the elliptical mode field of planar wave-guides. In this paper, we describe our results indicating that those fibres are not applicable in combination with standard mono-mode InP-based wave-guides.

Introduction

To achieve maximum coupling efficiency between a circular mode field of a fibre and the elliptical mode field of a planar wave-guide, these mode fields and the acceptance angle of both mediums have to fit. The mode field of the wave-guide can be transformed by a spot-size converter [1] and a lensed fibre tip can transform the mode field of the fibre. Mainly tapered hemi-spherical fibre tips are used. High coupling efficiency between optimized pump laser diode and wedged shaped fibre tips is published in [2]. Elliptically lensed fibre tips can also be fabricated with polarization maintaining fibres [3]. At the moment, there is no standard process for the integration technology for spot-size converters on InP, therefore we investigated the coupling efficiency between elliptically imaged fibre tips and standard mono-mode wave-guides.

Fibre types

The optical properties of two different fibre tips, types B and C are compared with a tapered hemi-spherical shaped fibre type A. (see figures 1-3).

Fig 1 Fibre type A

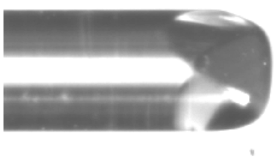

Fig. 2 Fibre type B

Fig. 3 Fibre type C

Fibre type A is tapered at an angle of 55° and on top is a hemi-spherical lens with a radius of 14.5 μm. Fibre B is chisel shaped and the radii of the lenses on the chisel tips vary from 5, 6, 7, 8, 9, 10, 11, 12, 15 and 20 μm. Fibre type C has two different radii perpendicular to each other. From the data of the manufacturer focused those two radii the infrared spot to an elliptical spot of 1.7 x 3.6 μm. All fibre tips are anti-reflect coated for 1550 nm.

Experimental Results

The measurement set-up is schematically showed in figure 4. A laser source (1) operating at 1550 nm is connected to a polarization controller (2). The input fibre tip (3), connected to the polarization controller, is mounted in a fibre holder (4), which can rotate on the optical axis of the fibre. This fibre holder is mounted on a 6-axis piezo-electric stage (5). The optical chip with straight wave-guides (7) is located on a removable stage (6). The output fibre (10) is also clamped in a fibre rotator holder (8). This device is mounted on a 3 axis piezo-electric stage (9). The output fibre (10) is connected to an optical power meter (11).

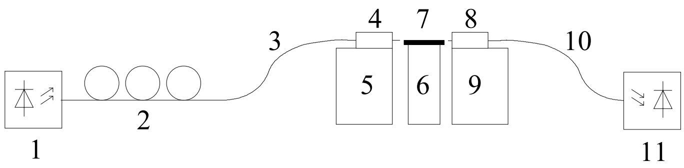

Fig. 4 Experimental set-up

Exp.	Input fibre	Wave-guide	Output fibre
1	A	No	A
2	B	No	B
3	C	No	C
4	A	Yes	A
5	A	Yes	B
6	A	Yes	C
7	A	Yes	A,B,C

Table 1

In table 1, the measurement scheme is given. The first 3 experiments investigate the optical properties of the different fibre types without the wave-guide. The input fibre is fixed and the output fibre is rotated 360° around his optical axis. Experiments 4 to 6 use the same procedure but with wave-guide and fixed input fibre type A. Experiment 7 investigates the lateral and transversal displacement of the different types of output fibres.

Experiment 1: Measured coupling losses are 0.7 dB. The measured loss in the connector, between fibre tip and polarization controller is 0.4 dB. So the loss between the two hemi-spherically lensed fibres with radii of 14.5 µm is 0.3 dB.
Experiment 2: In figure 5 the results are plotted. The coupling loss is the same or less than the reference spherical fibres of experiment 1. Fibre type B produced an elliptical spot when the radius of the lens was less than 12 µm. Fibre tips of 15 µm and 20 µm produced a circular spot. The coupling efficiency decreases when the radius of the fibre tips decreases.
Experiment 3: In figure 6 the results are plotted. As a result of the data included by the fibres, fibre pair 5-15, 6-7, 10-13 and 8-12 are formed to match the dimensions of the beam-waist diameters. The measured coupling efficiency is about 10 – 11 dB. An elliptically focused spot is also observed.
Experiment 4: The total system loss is 10.3 dB (see figure 7). The wave-guide loss is estimated 1.5 dB due to the length of the wave-guide, which is 12 mm. The coupling loss for one fibre wave-guide transition is 4.4 dB. This is also measured in [4].
Experiment 5: The total system loss is 12.8 dB determined for fibres with a lens radius of 5, 7 and 10 µm. Fibres with a lens radius of 12 µm and 20 µm showed system losses of 15,5 and 16,5 dB respectively. In figure 7, the measurement with fibre type B with a lens radius of 7 µm is also given. The influence of the lens radius to the coupling

efficiency and the difference in maximal and minimal coupling loss as a function of the axial rotate position is given in table 2. If the lens radius is 10 µm or more, the coupling losses increase (column 2 table 1) and the beam profile changes from elliptical to circular (conclusion from column 2 table 2)

Experiment 6: The system loss using fibre type C is 10 dB at the ideal axial rotate position (figure 7).

Experiment 7: Translation of fibre type A in lateral and transversal directions shows almost the same profiles (figure 8). The near field profile of a wave-guide is elliptical, but the acceptance angle in transversal direction greater than in lateral direction. This probably can explain the same curves. The fibre lens type C has almost the same curve in transversal direction, but in a lateral direction the alignment tolerance is more critical. The alignment tolerance of fibre type B, with a lens radius of 5 µm, is less critical in lateral direction than fibre types A and C. In transversal direction the curve can be compared with fibre type C. The total coupling loss of fibre type B is about 2.5 dB more compared with fibre types A and C.

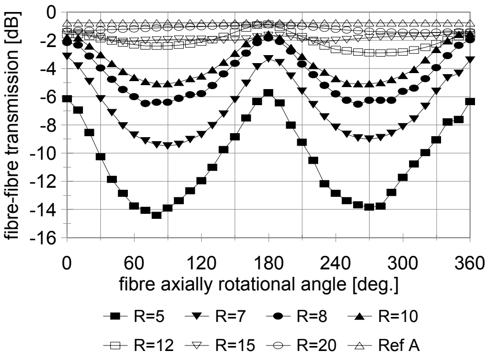

Fig. 5 Coupling characteristics fibre B - B

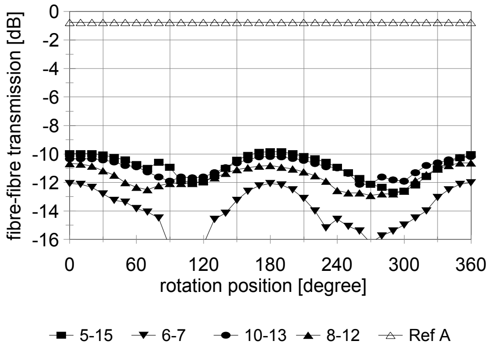

Fig. 6 Coupling characteristics fibre C - C

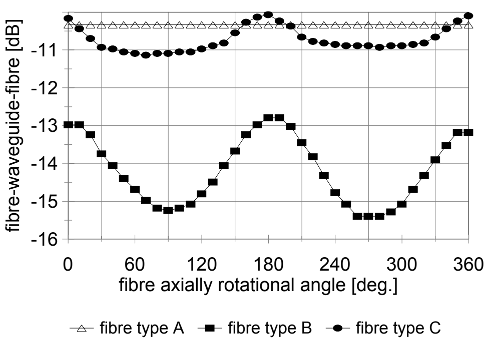

Fig. 7 System loss fibre A, B, C and wave-guide

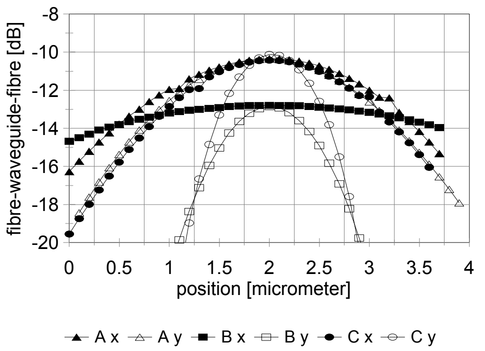

Fig. 8 x,y translation fibre type – wave-guide

Radius [µm]	System loss, fibre A – wave-guide - fibre B [dB]	Difference in relative transmission 90° axial rotate position fibre B- wave-guide [dB]
5	-12.7	3.3
7	-12.8	2.6
10	-12.9	1.5
12	-14.6	0.8
20	-16.5	0.05

Table 2 Measured system coupling loss of fibre type B and difference in minimal and maximal fibre-wave-guide coupling loss as a function of the different axial rotate position of fibre type B of 90°.

Far field power distribution measurements

The far field power distribution of the fibre type B is given in figures 9, 10 and 11 for fibres with a lens radius of 5, 10 and 20 μm respectively. If the radius is 5 μm, light appears out of the center in the direction of the curved surface (figure 9). This explains the increasing coupling loss if the radius decreases when the same fibre types are positioned opposite each other (experiment 2). If the fibre tip radius is 10 μm, the light distribution is regularly elliptical (figure 10). As we noticed earlier in experiment 2, the power field distribution become more circular instead of elliptical if the lens radius is 20 μm. This is also measured in the far field power distribution (figure 11). In figure 12 a typical far field distribution of fibre C is given. This explains the high coupling loss for both fibre tips opposite to each other (experiment 3).

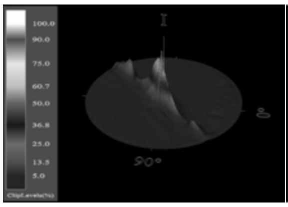

Fig. 9 Fibre B R=5μm

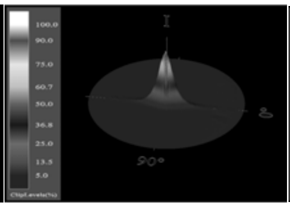

Fig.10 Fibre B, R=10 μm

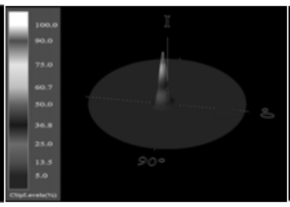

Fig.11 Fibre B, R=20 μm

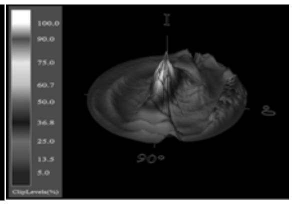

Fig. 12 Fibre C

The fibre type B wave-guide loss is about 2.5 dB higher compared with the spherical reference fibre (if the radii are 5-10 μm). So we can conclude that the elliptical beam-waist does not fit the optical properties of the wave-guide. The coupling loss between fibre type C and wave-guide is about the same as the hemi-spherical reference fibre. In spite of the far field distribution pattern of figure 12, the most energy is focused in the center of the fibre tip, which apparently fits the properties of the wave-guide, producing a surprisingly relatively good coupling efficiency between the fibre type C and the wave-guide. This in contrast to the high coupling loss of 10 dB between the same types of fibres opposite to each other (experiment 3).

Conclusions

Measurements establish that the new types fibres B and C presented in this paper do not have better coupling efficiencies and the 1-dB alignment tolerances are more critical compared with standard hemi-spherical lensed fibres in combination with standard mono-mode wave-guide dimensions of 3 x 0.6 μm.

The elliptical spot of fibre type B transforms into a spherical spot if the lens radius becomes 10 μm or more.

The total far field power distribution of fibre type C is not focused on-one elliptical spot.

References

[1] J. Stulemijer, A.F. Bakker, I. Moerman, F.H. Groen and M.K. Smit, "InP-based spotsize converter for integration with switching devices," *IEEE Photon. Technol. Lett.*, vol 11, pp. 81-83, Jan 1999.

[2] B. Sverdlov, B. Schmidt, S. Pawlik, B. Mayer and C. Harder, "1 W 980 nm pump modules with very high efficiency," in *Proc. 28th Eur. Conf. On Optical Communication*, 2002, PD3.6, pp. PD3.6-1-PD3.6-3

[3] W. Hunziker, E. Bolz and H. Melchior, "Elliptically lensed polarization maintaining fibres," *Electron. Lett.* Vol. 28, No. 17 pp. 1654-1656, (1992)

[4] J.H.C. van Zantvoort, C.G.P. Herben and H. de Waardt, "Multi-fibre to InP-based waveguides coupling efficiency determination," in *Proc. 2000 IEEE/LEOS Symp. Benelux chapter*, pp147-150.