Polymer Optical Motherboard Technology

N. Keil, H. H. Yao, C. Zawadzki, W. Schlaak, M. Möhrle, N. Grote
Fraunhofer-Institute for Telecommunications Heinrich-Hertz-Institut, Einsteinufer 37,
D-10587 Berlin, Germany, keil@hhi.fraunhofer.de

Abstract: *Using polymer optical motherboard technology, an optical transceiver and a minispectrometer integrating an optical demultiplexer with optoelectronic devices are described. Main issues including coupling from waveguide to photodiode, laser to waveguide, bonding, and fibre to motherboard coupling are discussed.*

1. Introduction

Integration and miniaturization have always been the dream for engineers. They offer the path to low cost, high reliability and modularized products. Optical integration has not progressed as fast as electronic integration in the past years. One of the main reasons is that for integrated optics it is difficult to use only one material system to fabricate optimal devices with a wide range of functions.

Polymer waveguide devices are attractive because they offer the potential of fairly simple and low cost fabrication based on low-temperature processes and low cost packaging based on passive alignment [1-3]. The optical loss of optical polymers has been reduced to less than 0.1dB/cm recently [4]. Polymer optical waveguide device can provide a convenient integration platform including optical waveguide devices and optoelectronic chips.

In this paper, a PLC based optical transceiver and a minispectrometer are addressed. The transceiver is shown schematically in Fig. 1. The coupling from the polymer waveguide to the photodiode (PD) as well as from the laser diode (LD) to the polymer waveguide is accomplishhed via a 45° mirror (vertical coupling). The light from the LD can also be coupled to polymer waveguide by butt-joint coupling. For reducing cost, passive alignment of fibre-chip coupling is possible by U-grooves. These main issues will be discussed.

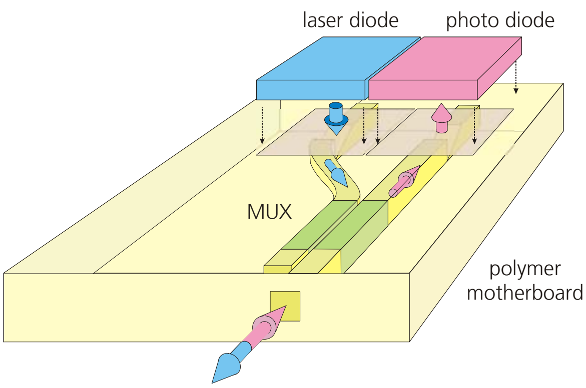

Fig. 1: Optical transceiver in polymer optical motherboard technology.

2. Optical transceiver

Fig. 2 shows a photo of the polymer optical motherboard of a PLC transceiver chip, Fig. 3 shows the chip layout.

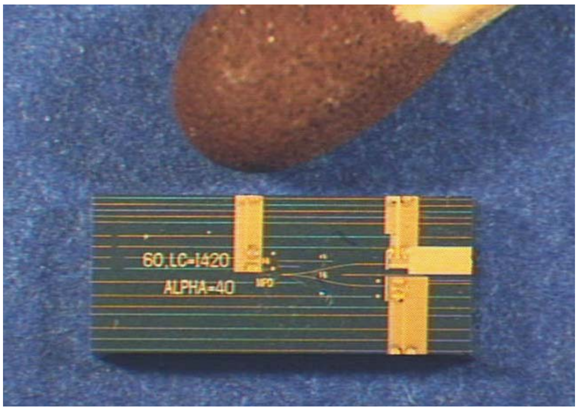

Fig. 2: Polymer optical motherboard of a PLC transceiver.

For achieving a high coupling efficency between the laser diode and the polymer waveguide, a polymer waveguide with a super-high refractive index contrast of Δn=0.020 and a dimension of 2.5 µm x 2.5 µm was used. The small waveguide dimension renders the waveguide to satisfy the strict single-mode conditions.

A directional coupler (DC) is used as a wavelength multiplexer. The DC is designed to have a bar-state at the 1310 nm upstream channel, and a cross-state at the 1490 nm downstream channel. The DC has a very compact size with a length of the coupling reagion of only 1.4 mm. A LD, a PD and a monitor photodiode (MD) are hybridly integrated on the polymer motherboard. The coupling from the polymer waveguides to the PDs as well as from to the LD to the polymer waveguide is accomplished via 45° mirrors. The chip size is only 3 mm x 7 mm.

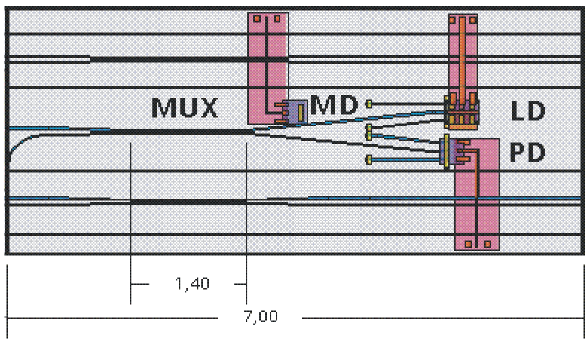

Fig. 3: Chip layout of a PLC transceiver.

3. Coupling of photo diodes (PD)

The downstream light at 1490 nm is coupled to the PD via a 45° mirror [5]. Fig. 4 shows the cross-section of a schematic picture of this coupling concept. The spot size of the above polymer waveguide is only 1.92 µm. This spot size will be expanded after propagating a distance in the mirror space. Fig. 5 shows the calculated beam size. It can be seen that even after 100 µm, the beam size is still less than 25 µm in the free space region at the mirror. If the mirror space is filled with polymer, the beam size reduces to about 15 µm. In our design, the propagation distance is less than 20 µm, resulting in a beam diameter of less than 10 µm, which is smaller than the active diameter of a PD used for 10 Gbit/s reception.

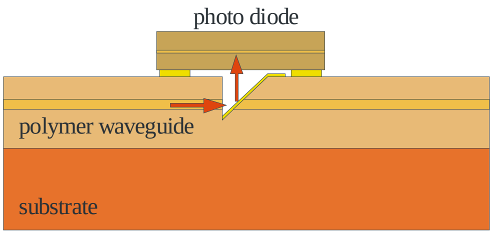

Fig. 4: Vertical coupling between waveguide and PD.

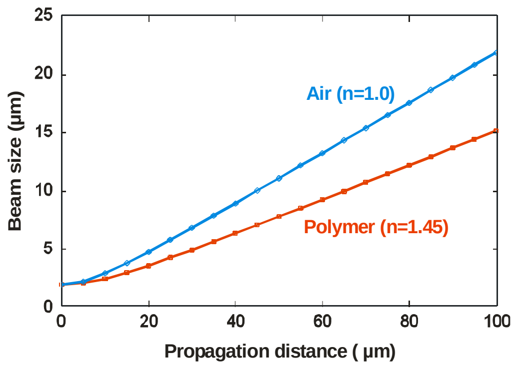

Fig. 5: Beam size of polymer waveguide after propagating a distance in the free space region at the mirror.

This vertical coupling concept has also been used in a miniature optical spectrometer. The spectrometer consists of a polymer arrayed-waveguide grating (AWG) that is fabricated on a polymer substrate, and an array of InP photo detectors (PD) that are hybridly integrated as shown in Fig. 6. The output beams of the AWG are vertically coupled to the PD array via a 45° mirror. Fig. 6 shows microscopic pictures of three detectors of the PD array and the cross-section of a 45° mirror for vertical coupling.

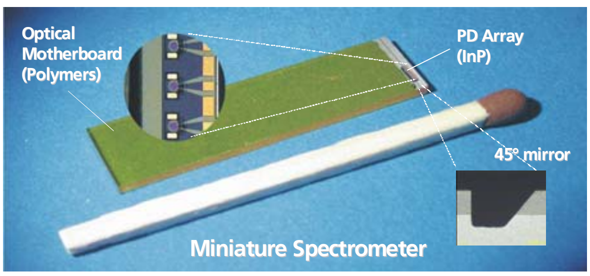

Fig. 6: Miniature optical spectrometer.

This miniature spectrometer can find wide applications as optical channel performance monitor in WDM (wavelength division multiplexing) networks, as wavelength meter and sensors in IR instruments.

4. Coupling of laser diodes (LD)

For an efficient coupling between a Gaussian beam of a LD and a polymer single-mode waveguide, the optical mode profiles of the LD and the polymer waveguide should be overlapped as much as possible [6]. The coupling can be accomplished by vertical scheme or butt-joint coupling.

4.1 Vertical coupling scheme

The main advantage of this scheme is easy adjustment of the laser diode because it avoids the adjustment in the vertical direction allowing automatic assemble using pick and placer. Fig. 7 shows the cross-section of the coupling scheme.

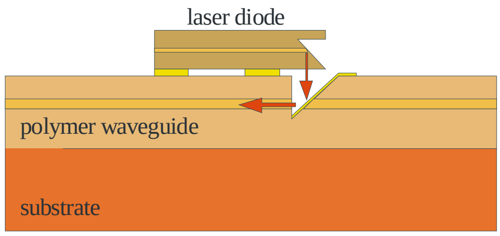

Fig. 7: Vertical coupling between waveguide and LD.

As it can been seen from Fig. 7, the laser beam has to travel a distance before entering the waveguide. For effective coupling this distance should be as small as possible. In our design, it was chosen to be ~ 15 µm. Fig. 8 shows the calculated coupling loss vs. the mirror deepness when the gap in the mirror is filled with polymer. The coupling loss depends strongly on the type of LD used. A typical ordinary LD has a far-field angle (FWHM: full width at half maximum) of about 32° in the lateral and 39° in the longitudinal direction. A tapered LD has divergence angles of 15° in the lateral and 20° in the longitudinal directions, respectively. The coupling loss of ordinary LDs is very high. Thus, a low-loss transceiver must use LDs with narrow divergence angles. If the space in the mirror is filled with air, the coupling loss is about 1-2 dB higher. From above discussion, a tapered LD and a polymer waveguide with $\Delta n = 0.020$, W=d= 2.5µm was chosen in our design of a low-loss transceiver.

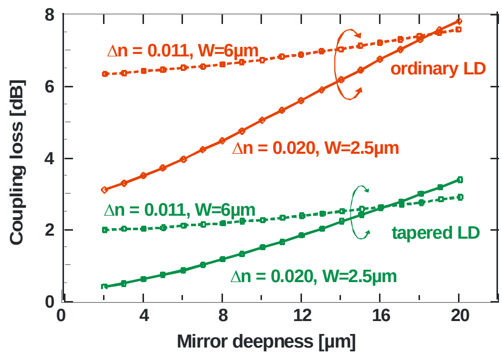

Fig. 8: Calculated coupling loss vs. mirror deepness for different LDs and polymer waveguides.

4.2 Butt-joint coupling

Fig. 9 shows the simplest approach of LD to single-mode fibre (SMF) coupling by butting a fibre to LD, which has a high coupling loss of 7 to 10 dB. For reducing this loss, different methods such as lenses and tapered fibre have been be used. In principle, such means serve as spot-size converter.

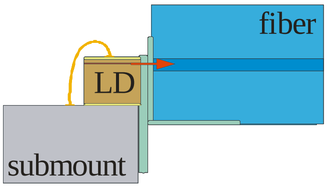

Fig. 9: Butt-joint coupling between a LD and a SMF.

A piece of polymer waveguide can be used as a spot-size converter as depicted in Fig. 10. From calculation, the coupling loss between a LD with far field angles of 27° in lateral direction and 47° in longitudinal direction to SMF is 9.7 dB. However, if this LD is coupled via a polymer waveguide the coupling loss amounts to about 3.5 dB only.

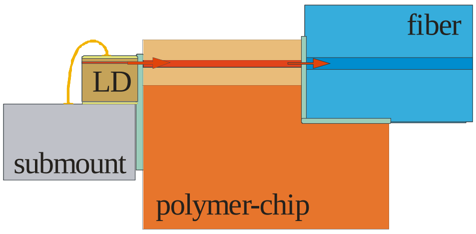

Fig. 10: Butt-joint coupling between a LD and a SMF via a polymer waveguide serving as a spot size converter.

Fig. 11 shows the calculated coupling loss between polymer waveguide with a high index contrast and LDs of different beam divergences. The allowed lateral mismatch for 1 dB tolerance is about 1 μm.

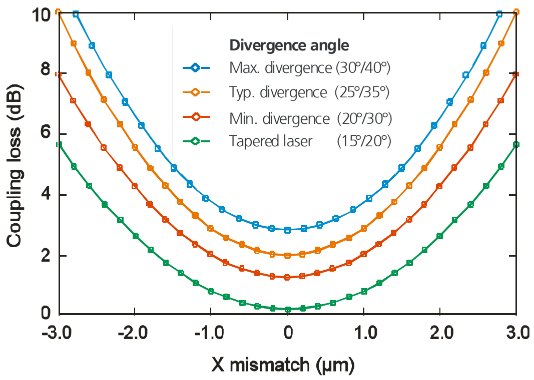

Fig. 11: Calculated coupling loss between LDs and polymer waveguide vs. lateral off-set.

For polymer waveguides with a refractive index difference of Δn = 0.020, the fibre-to-chip coupling loss is about 1.6 dB at 1.49 μm and 2 dB at 1.31 μm wavelength, respectively. In order to further reduce this coupling loss, a laterally tapered waveguide can be incorporated. The coupling loss depends strongly on the taper width (see Fig. 12). The loss can be reduced to only 0.25 dB at λ=1.49 μm if the width of the taper is only 1 μm. For λ=1.31 μm, the width of the waveguide taper should be reduced to 0.8 μm for obtaining a coupling loss of 0.25 dB [7].

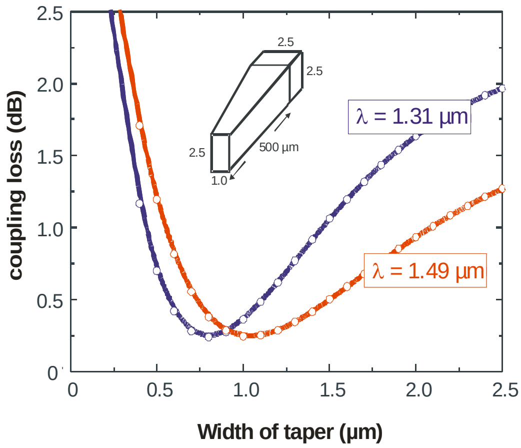

Fig. 12: Calculated coupling loss between SMF and polymer waveguide vs. width of taper.

These calculated values agree well with experimental results. Fig. 13 shows the photo of a LD with 27°/47° divergence angles coupled to a polymer waveguide. The measured coupling loss between LD and fibre was only 4.0 dB, which is close to the calculated value of 3.5 dB. For a LD with 20°/40° divergence angles the calculated loss value is 3.2 dB, and the measured one is 3.5 dB.

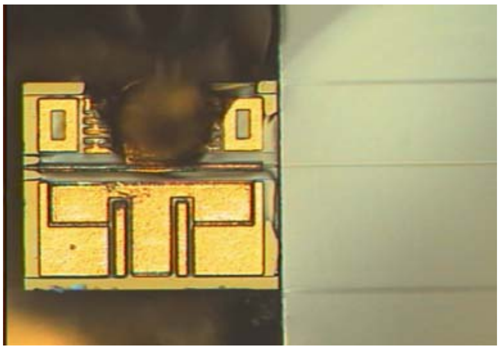

Fig. 13: A LD chip is coupled to a polymer waveguide.

5. Bonding

Fig. 14 shows a wire bond between a polymer chip and a submount using ultrasonic bonding. Pull tests show that the bond meets the MIL standard.

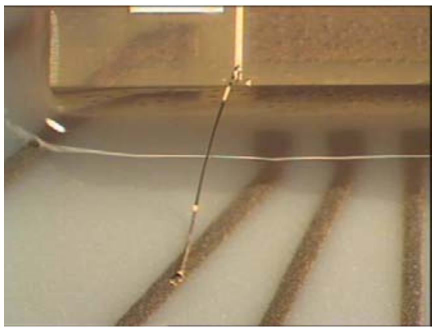

Fig. 14: Wire bonding.

6. Fibre/chip coupling

6.1 Fibre-array with polymer substrate

As we demonstrated earlier, the wavelength tuning behaviour of a polymer arrayed-waveguide grating (AWG) can be adjusted by choosing a suitable combination of TO (thermo-optic) coefficient of the polymer waveguide and the CTE (coefficient of thermal expansion) of the polymer substrate. It is possible to realize negative, positive and athermal tuning behaviour. An athermal AWG has been realized using this all-polymer approach at HHI [8], which also helps to control the polarization behaviour [8].

When an AWG on a polymer substrate is connected to a commercial silicon-based fibre-array, the mismatch between the CTE values of polymer and silicon may additional loss. Therefore, a fibre-array with polymer substrate was developed. Fig. 15 shows a photo of a all-polymer fibre-array with eight fibres.

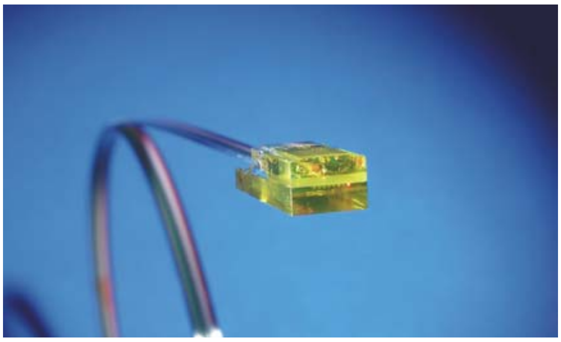

Fig.15: All-polymer fibre-array.

The fibres are inserted and guided in V-grooves that are fabricated by micro machining the polymer substrate, as shown in Fig. 16. This simple fabrication procedure allows for very low manufacturing costs. The core-to-core pitch is 250 µm. The cover plate is also made of polymer material. The end face of the fibre-array was polished to ensure low-insertion loss. The CTE of the fibre-array can be perfectly matched to the CTE of polymer waveguide devices if the same polymer substrate is used. Therefore, this all-polymer fibre-array is useful for packaging waveguide devices with polymer substrates.

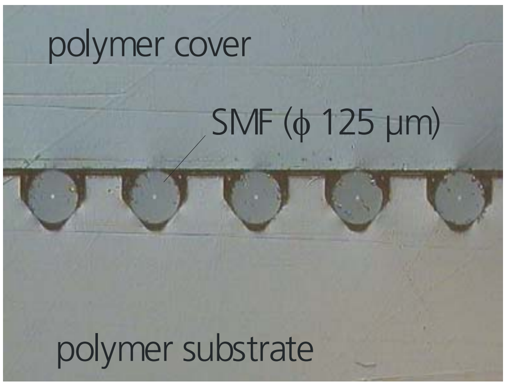

Fig.16: All polymer fibre-array.

6.2 Passive alignment

By using an alignment-free coupling scheme (called passive alignment), the cost of coupling optical SMF to polymer motherboard may be significantly reduced. Fig. 16 shows conceptiually how a U-groove may be formed in the same substrate as the polymer motherboard for aligning and fixing the fiber.

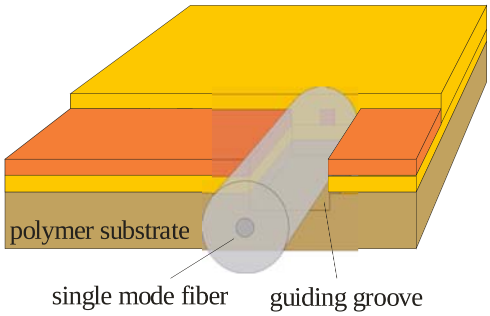

Fig.17: Sketch of a single-mode fibre coupled to a polymer waveguide using a guiding groove structure.

Conclusions

Polymer optical motherboards integrating polymer planar light wave circuits and optoelectronics devices such as laser diodes and photo diodes have been investigated. Good coupling efficiency between optical polymer waveguide and the optoelectronics devices were demonstrated. Simple alignment using a vertical coupling scheme or butt-joint coupling and passive alignment for fibre-chip coupling are possible.

Polymer motherboards may also be made incorporating thin-film filters (TFF), Bragg gratings, or many other features to produce hybrid integrated devices to be used as optical transmitter, receiver including D(Q)PSK receiver, optical transceiver, OTDR, etc..

Acknowledgments

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References

1 S. Lehmacher et al, Electron. Lett., no. 12, p. 1052, 2000.

2 A. Rogner et al, OFC, Paper FB1, pp. 279, 1994.

3 J. T. Kim et al, ECOC Paper Th1.4.2, p. 806, 2004.

4 A. Yeniay et al, J. Lightwave Technol., no. 1, p. 154, 2004.

5 J.-W. Park et al, Photonic Techn. Lett., no. 4, p.807, 2005

6 M. Saruwatari et al, Applied Optics, no.11, p.1847, 1978.

7 T. Mizuno et al, J. Lightwave Technol., no. 3, p. 833, 2004.

8 N. Keil et al, ECOC Paper Tu3.5.3, p. 252, 2003.