Polymer PLC as an Optical Integration Bench

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Abstract: A polymer-based photonic toolbox is presented, in which fiber grooves, waveguides, thin film elements and 45°mirrors can be combined for hybrid integration with active components. The toolbox provides solutions for polarization control and 90°hybrids.

OCIS codes: (250.5300) Photonic integrated circuits; (250.5460) Polymer waveguides; (310.6845) Thin film devices and applications

1. Introduction

Optical integration has regained much attraction recently as it is considered to substantially meet future requirements and challenges of optical devices. Although large effort is now being spent on monolithic integration technologies on both InP and Silicon, hybrid integration is a powerful competitor because of the high freedom of performance and yield optimization, relative cost-efficiency, and it’s versatility which makes it particularly useful for low/ medium production volumes. Different PLC platforms have been investigated as basis for hybrid integration including silica-on-silicon, siliconoxynitride, glass, and polymers [1-4]. Using the latter option we have been developing and steadily extending an integration “toolbox” that allows implementing a broad range of passive and active optical components of interest to telecom/datacom and optical interconnects but also to sensors, metrology and the like.

2. Toolbox concept PolyBoard

Our “PolyBoard” integration approach comprises the following features, as illustrated in Fig.1:

- Passive fiber attachment using etched U-grooves
- Use of extremely thin “thin film elements” (T2FE) to implement various passive optical functions
- Surface-mount photo detectors as well as surface emitters utilizing integrated 45°turning mirrors
- Butt-joint coupling of edge-emitting laser devices

Following a strategy of widely performing passive optical functionalities by means of T2FE’s (Fig. 1a) rather than waveguides offers a substantially higher degree of compactness, temperature insensitivity, and design flexibility. Basically, in this concept the role of the PLC waveguides is limited to on-chip guided wave optical interconnection.

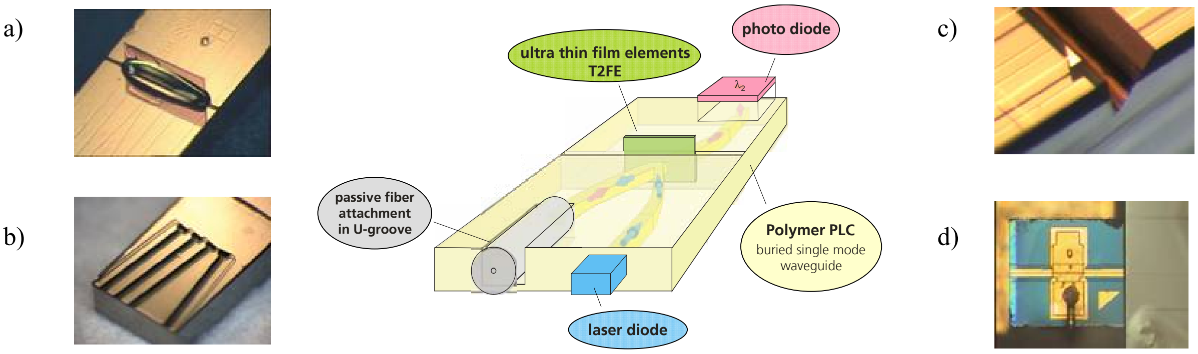

Fig. 1 PolyBoard toolbox concept: (a) T2FE inserted in waveguide slot; (b) U-grooves for passive fiber coupling; (c) integrated 45°turning mirror for coupling of planar photo detectors; (d) butt-coupled edge emitting laser diode

The polymer material used is commercially available and exhibits a typical waveguide loss of ~0.5 dB/cm at 1550 nm and ~0.3 dB/cm at 1310 nm. Fiber alignment grooves integrated in the PolyBoard chip allow for passive fiber coupling and thus for cost efficient assembly (Fig.1b). A typical loss value is ~0.2 dB per-facet over a broad spectral range from 1200-1600nm. The accuracy of the width and depth of the U grooves is within +/-1µm over a 4” wafer. The 45°mirror (Fig. 1c) can be created either by micro-machining or grey-tone mask lithography and subsequent reactive ion etching. Photo detectors are placed on top of the PolyBoard waveguides by a state-of-art bonder with ~1µm positioning precision. Butt-joint coupling of edge-emitting lasers is achieved by active alignment (Fig.1d).

3. Passive components

Dedicated thin film elements (T2FE) inserted into well adapted waveguide slots enable spectral filtering, wavelength (de)multiplexing, polarization handling, and other optical functions. The slots are formed either by micro-machining or reactive ion etching, subject to wafer and chip layout. Recently, a 1×2 1310/1550nm (de)multiplexer with an insertion loss of around 1dB was demonstrated [5]. As another exemplary application, a very compact (0.7x3mm^2) OTDR chip has been developed (Fig 2a). The OTDR element exhibits a spectral band edge at 1610 nm suitable for reflecting OTDR signals at $\geq$1625 nm wavelength leaving all other wavelength (1260-1580nm) unaffected (Fig.2b). These chips can be used to remotely monitor the connectivity and termination status of passive fiber optical networks, and to identify with high spatial resolution any point of failure that may degrade transmission performance (Fig. 2c).

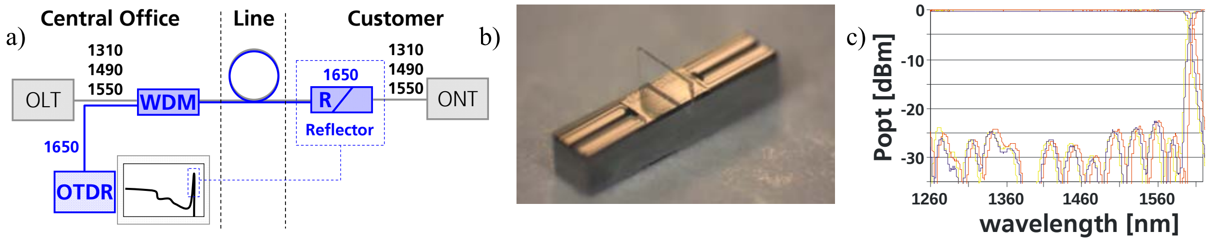

Fig. 2 (a) OTDR monitoring of passive optical networks; (b) OTDR PolyBoard; (c) spectrum of bare T2FE

First polarization beam splitters (PBS) were realized as sketched in Fig. 3a/b.TE polarization is reflected to output 1 and TM is transmitted to output 2. Fig. 3c shows the wavelength dependence of the TE and TM signals at both outputs. The splitting ratio is >20dB within a 1535-1600nm window. The performance in terms of insertion loss and polarization splitting bandwidth will be further improved by optimizing the waveguide/T2FE interface.

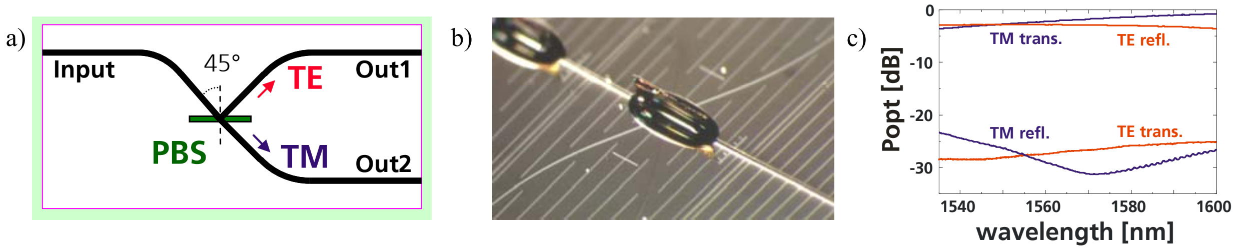

Fig. 3 (a) Polarization beam splitter (PBS) implemented on PolyBoard; (b) PBS PolyBoard; (c) measurement results.

Delay line interferometers (DLI) used to convey PSK signals into an ASK signals often require very low PDFS values. One way to compensate PDFS is to insert a λ/2-wave plate into these chips [6]. Fig. 4a shows the layout of a polymer-based DLI composed of a Y-branch and a 2x2 MMI with a half-wave plate inserted. The residual PDFS of this device is measured to be 1.7 GHz (Fig. 4b). To further reduce the PDFS thermal electrodes have been added on top of the polymer PLC for thermo-optical control. With a heater current of 8mA, PDFS could be totally eliminated. Further increase of the current leads to reverse the PDFS.

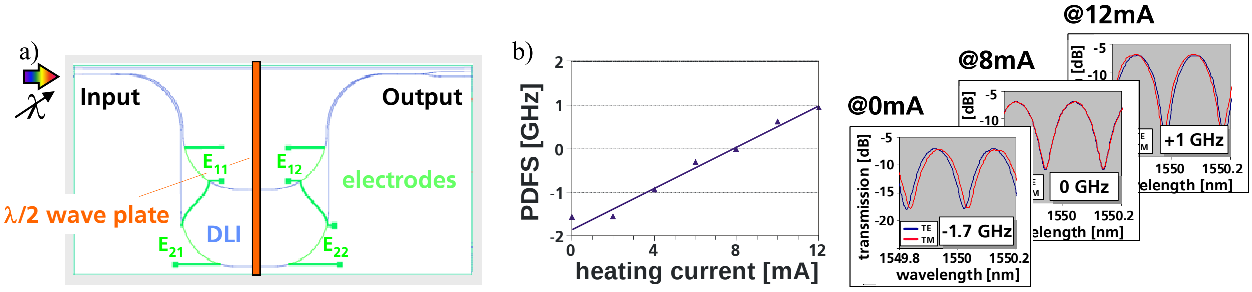

Fig. 4 (a) DLI with λ/2 plate and heating electrodes for PDFS control; (b) PDFS of DLI at different heating current.

4. Hybrid integration of active devices

InP-based laser diodes and photo detectors can be hybrid-integrated via conventional butt-joint techniques or in a surface-mount manner via integrated 45°mirrors, the latter offering the possibility of automated wafer-scale assembly. Fig. 5a shows the butt-joint coupling of a DFB laser diode to the PolyBoard and Fig. 5b the optical output characteristics measured ex fiber. At 100mA 16mW of output power were achieved implying 3 dB coupling loss. The spectrum (Fig. 5c) shows a single mode suppression ratio >40dB which holds over the full drive current range.

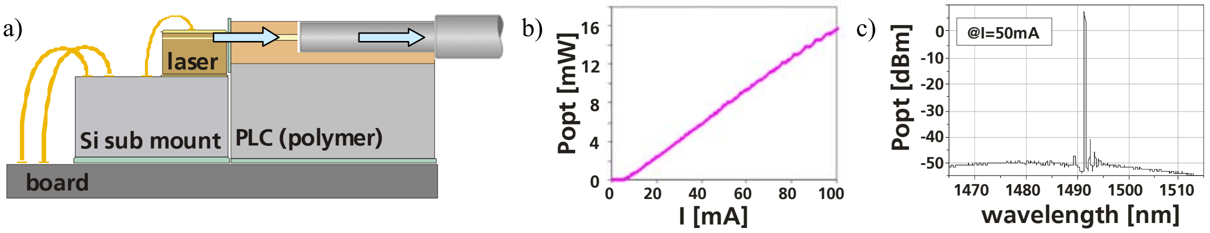

Fig. 5 (a) Butt coupling of DFB laser to PolyBoard; (b) measured P-I curve (ex fiber); (c) output spectrum (ex fiber)

Fig. 6a shows the top view of 4-channel fiber-waveguide-detector array (PDA) suitable for 25 GB/s detection (20µm diam.). The center spacing between the waveguides is 250µm allowing the use of standard fiber ribbons. The PDA was mounted in a passive way above the 45°mirror. The measured responsivity varied between 0.35-0.43A/W to be compared to 0.65A/W obtained from direct fiber illumination. Fig. 3b shows the small signal frequency response of a mounted PD chip reaching a 3dB bandwidth of 25 GHz. The measurement was performed directly on the chip using a suitable RF probe head without extra electronics for 50Ω impedance matching.

90°hybrids are key components for DPSK receivers. Waveguide-based 90° hybrids have attracted attention due to its compactness and the mature assembly technology with balanced PDs [7]. We have designed a DLI integrated with a 90° hybrid structure. The hybrid itself was realized by a 2×4 MMI or 2 paired 2×2 MMIs. The chip size measures 20x4 mm^2. The measured phase characteristics and the transmission spectra at the four outputs are shown in Figs. 6c and 6d, respectively. The insertion loss amounts to 7.5 dB including the intrinsic 3dB loss of the MMI itself. The transmission imbalance among the four outputs is <0.3dB, and the phase error well below ±5° (Fig 6e).

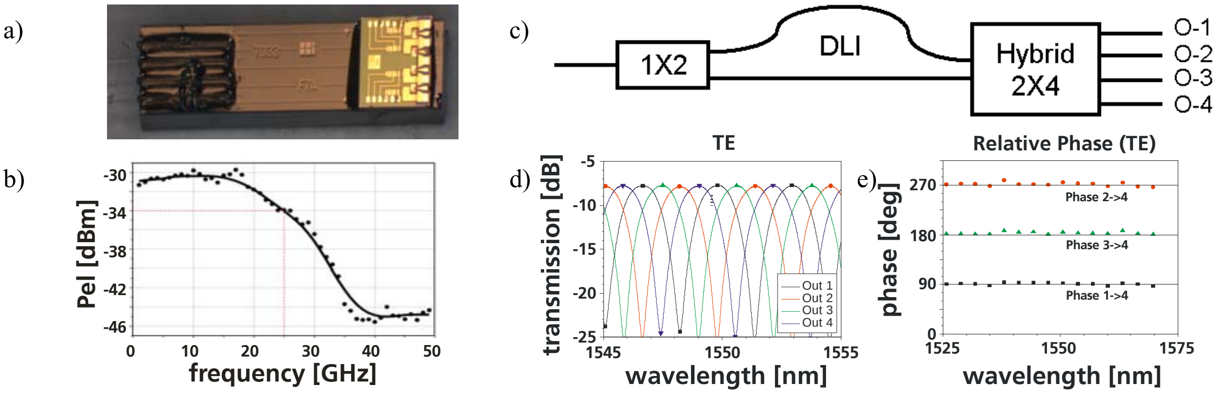

Fig. 6 (a) 4ch PolyBoard with 4x25Gbps PD array incl. bias T; (b) small signal frequency response of one PD; (c) scheme of a 90°hybrid with DLI; (d) transmission spectra at the four output ports; (e) phase error.

Reliability tests according to Telcordia standards (temperate cycling from -40 to +85°C for 1500 hrs, damp heat at 85%°C/85%RH for 1500 hrs, and high optical power of +23dBm/85°C for 4000 hrs) have shown promising results.

5. References

[1] L. Zimmermann et al., IEEE Photon. Technol. Lett. **21**, pp. 143–145 (2009).
[2] H. G. Bach et al., OFC 2009, paper OMK5 (2009).
[3] Y. Noh et al., Opt. Express **16**, pp. 18194-18201 (2008)
[4] N. Keil et al., Photonics West 2008, invited paper 6899-37 (2008).
[5] N. Keil et al., Electron. Lett. **45**, pp. 1167-1168 (2009).
[6] C. R. Doerr et al., OFC 2006, paper PDP9 (2006).
[7] S.-H. Jeong et al., Opt. Lett. **34**, pp. 3505–3507 (2009).