Low-Loss and High-Bandwidth Multimode Polymer Waveguide Components Using Refractive Index Engineering

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Abstract: Low-loss and high-bandwidth (>47 GHz•km) multimode polymer waveguide crossings (<0.02 dB/crossing) and bends (<1dB) are demonstrated. The performance of passive optical backplanes comprising such components is also optimised using refractive-index engineering and launch conditioning.

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1. Introduction
To meet the ever increasing demand for higher interconnection data rates within data centres and high performance computing environments, short-reach optical interconnects have attracted significant research interest over the past few years. Optical interconnects provide significant advantages over their conventional electrical counterparts: higher information capacity, lower power consumption, lower crosstalk and higher data density [1]. In particular, passive optical backplanes based on multimode polymer waveguides are considered to be a cost-effective solution in achieving high-speed interconnection between electrical cards in blade servers and data storage systems. Such backplanes benefit from the use of multimode polymer waveguides that allow direct integration onto low-cost printed circuit boards (PCBs). The waveguides typically have relatively large dimensions (30-70 µm) in order to offer relaxed alignment tolerances and therefore enable system assembly using common pick-and-place tools [2, 3]. Such optical backplanes may implement non-blocking interconnection architectures and feature complex waveguide layouts which include large numbers of on-board passive waveguide components such as bends and crossings [4, 5]. For example, the 1-Tb/s aggregate-capacity 10-card optical backplane presented in [4] features ~1800 waveguide crossings and 100 90° waveguide bends. These two elementary waveguide components however exhibit differing behaviour with respect to the waveguide refractive index (RI) difference Δn: waveguide bend loss benefits from strong optical confinement, whereas waveguide crossings exhibit lower loss and crosstalk for smaller Δn values. The RI profile of the particular siloxane waveguides employed in this work can be readily adjusted by slightly changing their fabrication parameters [6]. In this paper therefore, we present studies on these waveguide components and investigate their loss and bandwidth performance for different RI profiles. Excellent optical transmission properties are obtained while it is shown that appropriate RI engineering and launch conditioning can provide optimised loss and bandwidth performance for a waveguide layout that comprises a number of such components. The results demonstrate the strong potential of this multimode polymer waveguide technology and highlight their highly flexible structural design in forming high-capacity passive optical backplanes.

2. Waveguide samples and experimental setup
Three waveguide samples (denoted as WG01, WG02 and WG03) are fabricated with a slightly different RI profile and size using standard photolithographic processes on 8-inch silicon substrates from siloxane materials (Dow Corning WG-1020 Optical Waveguide Core and XX-1023 Optical Waveguide Clad). Each waveguide sample comprises waveguide components with (i) two 90° bends with a varying radius of curvature, (ii) a varying number of 90° crossings and (iii) reference waveguides [Fig. 1(a)]. The reference waveguides are used as control samples to compare the loss performance of the waveguide components and measure their bandwidth (BW). Fig. 1(b) shows the RI profile of the 3 samples at 850 nm while Fig. 1(c) summarises their key characteristics.

Fig. 1 (a) Schematic of the components studied and (b) the RI profile at 850 nm and (c) table with key parameters of the 3 waveguide samples.
The loss and BW performance of the waveguide components and reference waveguides is investigated under two different launches (a) a restricted excitation: a 9/125 µm single-mode fibre (SMF) input (loss measurements) or a 10x lens input (BW measurements) and (b) a typical multimode launch encountered in real systems: a 50/125 µm multimode fibre (MMF) input [numerical aperture (NA): 0.2]. All loss measurements are carried out at 850 nm using a VCSEL, while for the BW measurements, a 1574 nm mode-locked fibre laser (TOPTICA FFS) and a SHG crystal are used to generate short pulses (~400 fs) at 787 nm. A pair of microscope objectives is used to couple the emitted light into the input fibre, while the other end of the fibre is butt-coupled with the waveguide input. At the waveguide output, a 16x microscope objective (NA: 0.32) is used to collect the transmitted light and deliver it either to an optical power meter for loss measurements or to a matching autocorrelator for pulse broadening measurements. The waveguide BW is estimated based on the observed pulse broadening after transmission over the waveguide.

3. Experimental results
The bending (BL) or crossing loss (XL) of the waveguide components is obtained by normalizing their insertion loss (IL) with respect to the IL value obtained for the respective reference waveguides under the same launch condition. Fig. 2(a) and 2(b) show the excess loss in the components due to the waveguide crossings and bends for the two launch conditions studied. The MMF input couples a larger percentage of optical power at the waveguide input to the higher order modes, which are more susceptible to radiation loss in the bends and at the crossings, and therefore result in higher component losses than the SMF input. WG02 exhibits the highest BL as it has the largest width (~55 µm) and lower index difference Δn (~0.01). The other 2 samples exhibit a BL < 1 dB for a bend radius of > 6 mm for both launches. On the other hand, WG02 exhibits the lowest XL (~0.007 and 0.02 dB/crossing for the SMF and MMF launches respectively) due to its low Δn, whereas WG01 shows the highest XL value: ~0.093 and 0.1 dB/crossing for the SMF and MMF launches respectively. Fig. 2(c) summarises the obtained results as well as the IL and bandwidth-length product (BLP) of the reference waveguides for the 3 samples and inputs studied. For the 50 µm MMF input, WG02 exhibits the largest IL (~1.5 dB higher than that of WG01/WG03), but also the largest BW (~2.5 over WG01/WG03) due to its lower Δn. A restricted launch however, results in similar IL for all samples and high BLP >100 GHz×m due to the low input coupling loss and the excitation of lower order modes.

4. Conclusions
Multimode polymer waveguide crossings and bends with low loss performance and high bandwidth are demonstrated (XL<0.02 dB/crossing, BL<1 dB for R > 6 mm, BLP > 47 GHz×m). The component studies highlight the design trade-offs with respect to the RI profile and indicate the potential to combine RI engineering and launch conditioning in optimising the loss and bandwidth performance of complex waveguide paths that include a number of such components. Given the stringent power budget requirements in high-speed (≥25 Gb/s) optical links, the optimisation of the layout and launch becomes particularly important in the design of passive optical backplanes.

5. Acknowledgements
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6. References

Fig. 2. Excess loss of (a) the 90° crossings, and (b) the 90° bends for both launch conditions and (c) summary of results including the insertion loss and BLP (GHz×m) of the reference waveguides for the 3 samples.

(c) Performance metric | WG01 | WG02 | WG03
---|---|---|---
IL ref. WGs | 1.1 | 1.4 | 1.0
XL (dB/crossing) | 0.093 | 0.007 | 0.033
Radius for BL<1 dB (mm) | > 6 | > 10 | > 6
BLP ref. WGs (GHz×m) | 107 | 154 | 125
IL ref. WGs | 1.6 | 3.2 | 1.7
XL (dB/crossing) | 0.099 | 0.019 | 0.046
Radius for BL<1 dB (mm) | > 6 | > 11 | > 6
BLP ref. WGs (GHz×m) | 47 | 122 | 48

| Radius (mm) | 5 | 8 | 11 | 14 | 17 | 20 |
---|---|---|---|---|---|---|
BLP ref. WGs (GHz×m) | | | | | | |