Restricted Launch Polymer Multimode Waveguides for Board-level Optical Interconnects with >100 GHz×m Bandwidth and Large Alignment Tolerance

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Abstract: We report enhanced bandwidth performance of >100 GHz×m over an offset range of ±10 μm in multimode polymer waveguides under restricted launch, demonstrating the capability to support on-board data rates of >100 Gb/s.

OCIS codes: (200.4650) Optical interconnects, (130.5460) Polymer waveguides

1. Introduction

Short-reach optical interconnects have been of significant interest over the past few years for use in data centres, data storage systems and high-performance computing (HPC) systems due to the ever increasing demand for faster interconnection rates and higher bandwidth [1]. However, traditional electrical interconnection technologies impose a performance bottleneck owing to their inherent limitations when operating at high frequencies: low bandwidth, high losses and crosstalk and poor power efficiency [2]. Optical technologies provide an alternative solution to this interconnection issue, as they can offer higher bandwidth, immunity to electromagnetic interference and reduced power consumption in comparison to their electrical counterparts [3]. The deployment of optical technologies in next-generation high-performance electronic systems appears to be inevitable in order to address future bandwidth needs.

Multimode polymer waveguides are considered well suited for use in board-level interconnections. Particular polymer materials, such as siloxanes, exhibit excellent optical performance while allow direct integration onto printed circuit boards (PCBs) owing to their thermal and mechanical properties [4]. In addition, the use of large waveguide dimensions (typically 30 – 70 μm) offers relaxed misalignment tolerances, enabling therefore low-cost assembly using standard pick-and-place tools [5]. However, the highly-multimoded nature of these polymer waveguides raises important concerns about their capacity to support very high data rates in excess of 40 Gb/s. Dispersion studies have been conducted on such waveguides by various research groups with large bandwidth-length products (BLPs) being reported under restricted launch conditions. For example, values of 150 GHz (BLP: 75 GHz×m) for a 51 cm long waveguide and 1.03 GHz (BLP: 90 GHz×m) for a 90 m long waveguide have been measured [6, 7]. These measurements however, have been carried out only for a centre launch, while the effect of input offsets on bandwidth performance has not been studied. We have previously presented BLP values of >40 GHz×m and >70 GHz×m of two waveguide samples with different refractive index profiles under a 50/125 μm MMF launch [8]. In this paper, we report time domain measurements on such waveguide and matching simulation studies and demonstrate enhanced bandwidth performance for these polymer waveguides across different offsets under restricted launch. Our simulation and experimental results show that the BLPs can be larger than 100 GHz×m in an offset range of at least ±10 μm in both horizontal and vertical directions, demonstrating the practicality of the guides and their capability of transmitting >100 Gb/s data rates over a single waveguide channel.

2. Waveguide samples and pulse broadening measurements

The waveguide samples are fabricated from siloxane materials (Core: Dow Corning® WG-1020 Optical Waveguide Core; and cladding: XX-1023 Optical Waveguide Clad) on 8-inch silicon substrates using standard photolithography. The waveguide has length of 19.2 cm and a cross section of ~35 × 35 μm^2. Two waveguide samples are fabricated with different index profiles by controlling the fabrication parameters [9]: one has a step-like index profile (WG 1), while the other has a more gradual graded-like index profile (WG 2). Fig. 1(a) illustrates the structure of the waveguide sample. The refractive index (RI) profile of the two waveguides is measured using the refractive near field method and are shown in Fig. 1(b) and 1(c).

The dispersion study is based on time domain measurements, measuring the broadening of optical pulses after transmission over the polymer waveguide samples, and it is carried out with a short pulse laser second harmonic generation (SHG) system (Fig. 2). A femtosecond erbium-doped fiber laser source (TOPTICA FFS) operating at wavelength of ~1574 nm is employed as a pulse source, and an SHG nonlinear crystal (MSHG1550-0.5-1) is utilised to obtain pulses at the wavelength of interest (~787 nm). The output light from the SHG crystal is collimated by an aspheric lens (NA=0.55) and coupled to the waveguide input using a 10× microscope objective (NA=0.25). A 16× microscope objective (NA=0.32) is used to collect the light at the waveguide output and deliver it to an autocorrelator to measure the output pulse width. A translation stage and a displacement sensor are employed to control the input launch position in both horizontal and vertical directions. Fig. 2 shows the experimental setup for the waveguide link. The corresponding back-to-back link without the waveguide is also setup and tested in order to obtain the width of the reference pulse.

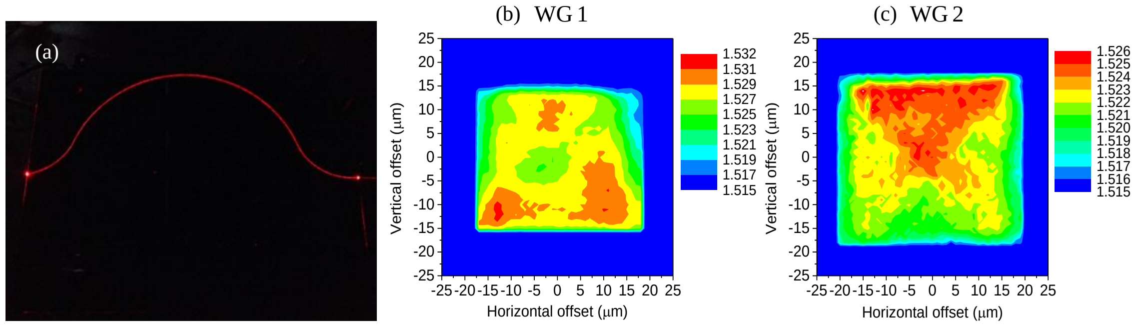

Fig. 1 (a) Top view of the waveguide sample illuminated with red light; and measured refractive index profiles of (b) WG 1 and (c) WG 2 at λ = 678 nm.

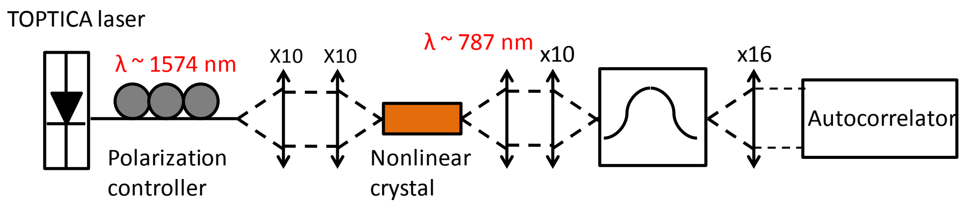

Fig. 2 Experimental setup for the waveguide link under a 10× microscope objective launch.

The received optical pulses after transmission over the link with and without the polymer waveguide are recorded for the different input launch positions. The received pulses are approximated with the best-matching common pulse shapes (e.g. $sech^2$, Lorentzian) using curve fitting and the frequency response of the back-to-back and waveguide links is calculated by taking their Fourier transform. The deconvolution between the two provides the frequency response of the waveguide, and thus their -3 dB bandwidth. The process is repeated for each input offset and a 2D plot of their -3 dB bandwidth is generated for each type of waveguide (Fig. 3). For WG 1, BLP values of >100 GHz×m are obtained for a region of area ~32 × 8 μm^2 in the lower bottom part of the waveguide core. For WG2, BLP values of >100 GHz×m are also obtained for a larger area of ~20 × 22 μm^2 in the upper bottom part of the core. These high-bandwidth regions are noted in red dashed line in Fig. 3. The results indicate that these waveguides can support very high data-rate transmission beyond 100 Gb/s under appropriate launch conditioning scheme and with relatively large alignment tolerances.

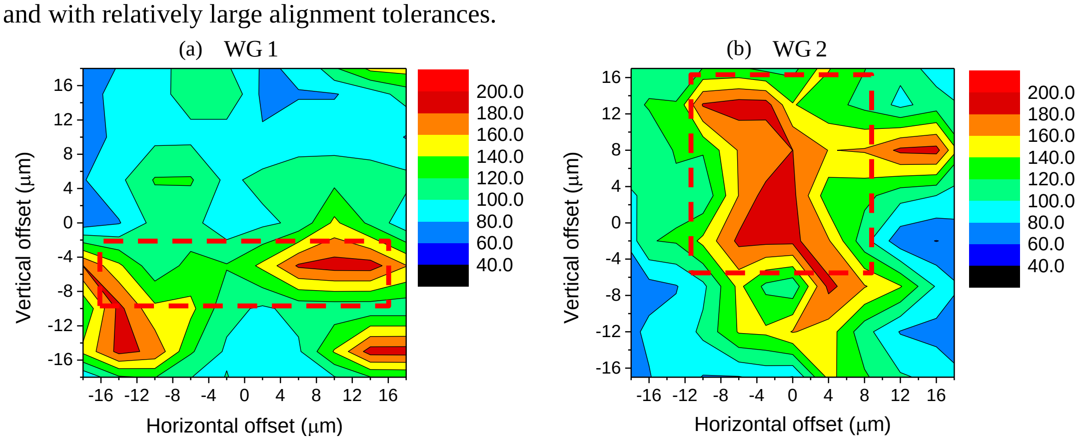

Fig. 3 Experimental results of BLPs (GHz×m) of (a) WG 1 and (b) WG 2 under restricted launch (high BLP region noted in red dashed line).

3. Simulation results

The dispersion performance of these guides is also studied by simulation. A commercial model solver (FIMMWAVE) is used to calculate the profile of guided modes together with their respective effective and group refractive indices based on their measured refractive index profile (Fig. 1). The mode power distribution inside the waveguide is obtained using the overlap integrals of the electric field of the respective waveguide modes and the incident beam at the waveguide input [10]. The beam profile generated by the 10× lens is modeled with a Gaussian field distribution with a spot size with a ~4 μm full-width-at-half-maximum (FWHM) (approximately the minimum achievable spot size using this lens). The impulse response of the waveguide can then be obtained by calculating the mode propagation delays and the waveguide bandwidth by taking its Fourier transform. The process is repeated for different launch positions and contour plots of the obtained -3 dB bandwidth are generated for each waveguide (Fig. 4). The simulation results are in general agreement with the experimental results. The BLP values of >100 GHz×m are found for a region of area ~32 × 6 μm^2 and ~28 × 22 μm^2 for WG1 and WG2 respectively (noted in red dashed line in Fig. 4). These regions match the areas of high RI at these launch positions as the small input spot excites only the lower order modes. This waveguide model, despite its simplicity, can therefore provide a useful tool for dispersion engineering and launch conditioning studies. Additional phenomena (e.g. mode mixing) that affect light propagation in the waveguide can be further incorporated in the model and provide a more accurate representation.

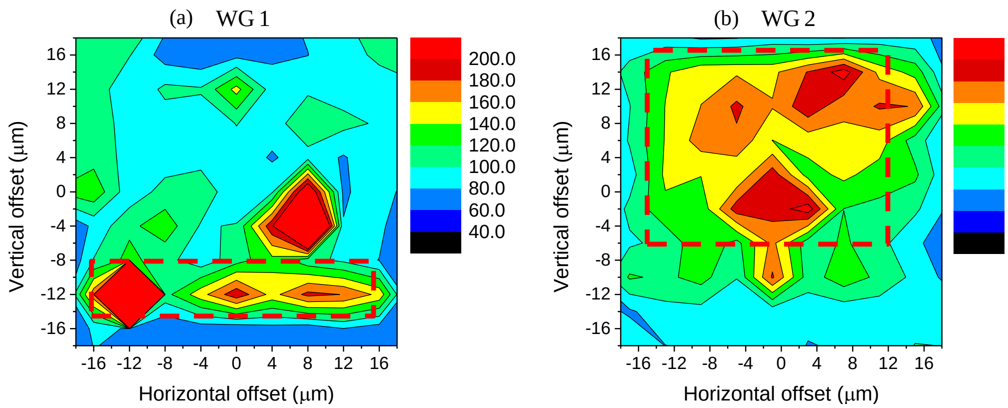

Fig. 4 Simulation results of BLPs (GHz×m) of (a) WG 1 and (b) WG 2 under restricted launch (high BLP region noted in red dashed line).

4. Conclusions

Pulse broadening measurements have been conducted on waveguide samples with different refractive index profiles. The experiments show that the BLP of these waveguides can be >100 GHz×m in a large area of input offsets of at least 10 μm × 10 μm under restricted launch. A simulation model is developed based on measured RI profiles and shows general agreement with the experiment. These results demonstrate the capability of transmitting >100 Gb/s data rates over a single waveguide using launch conditioning with appropriate refractive index engineering.

5. Acknowledgements

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