40 Gb/s Data Transmission over a 1 m Long Multimode Polymer Spiral Waveguide

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Abstract *We report record error-free data transmission of 40Gb/s over a 1m-long multimode polymer spiral waveguide. The waveguide imposes no significant transmission impairments in the link despite its highly-multimoded nature and long length, demonstrating its potential in high-speed board-level optical interconnections.*

Introduction

Optical interconnects based on polymer multimode waveguides have attracted particular interest in recent years for use in board-level communication links. Optical interconnects offer significant advantages over their electrical counterparts when operating at high data rates (≥ 10 Gb/s), namely large bandwidth, reduced power consumption, immunity to electromagnetic interference and relaxed thermal management requirements[1]. Polymer multimode waveguides offer the additional benefits that they can be directly integrated onto conventional printed circuit boards (PCBs) owing to the favourable material properties, and offer relaxed alignment tolerances in the assembly and packaging of these hybrid opto-electronic (OE) PCBs owing to the relatively large waveguide dimensions (typically in the range of 30 to 70 µm). Such waveguide-based optical links are particularly attractive for use in backplane and chip-to-chip interconnections with lengths in the range of 0.1 to 1 m. Various system demonstrators have been reported in recent years, featuring large arrays of PCB-integrated multimode polymer waveguides and low-cost, high-speed VCSEL sources, achieving high-aggregate on-board data capacities[2].

The continuous improvement in bandwidth performance of directly-modulated 850 nm VCSELs in recent years[3-5] indicates that even higher data capacities could be readily achieved for board-level optical interconnects. These improvements however, raise important questions on the bandwidth limitations of polymer waveguides due to their highly-multimoded nature. We have recently reported error-free ($BER<10^{-12}$) 25 Gb/s data transmission over a 1.4 m long spiral polymer multimode waveguide[6]. The performance of the optical link was power-limited rather bandwidth-limited due to the high insertion loss of the employed spiral waveguide (~13 dB). In this paper, we utilise a 1 m long multimode polymer spiral waveguide optimised for low loss operation and demonstrate the potential to achieve even higher data rates over such waveguide-based board-level optical interconnection links. Here, record high data rate error-free ($BER<10^{-12}$) data transmission up to 40 Gb/s over the spiral waveguide is reported, while it is shown that the waveguide exhibits a flat frequency response up to at least the 37 GHz instrumentation limit of our experimental setup.

Multimode polymer spiral waveguide

The 1 m long multimode spiral waveguide employed in this work is fabricated with standard photolithographic methods on an 8-inch silicon wafer from siloxane polymer materials (core: Dow Corning® WG-1020 Optical Waveguide Core and cladding: Dow Corning® OE-4141 Cured Optical Elastomer). These materials exhibit favourable properties for direct integration onto PCBs and are compatible with 850 nm VCSELs[7]. They can withstand the high temperatures (in excess of 260℃) required for solder reflow process and exhibit very low loss of ~0.04 dB/cm at 850 nm. The waveguide cross section measures approximately 32×50 µm^2, while the index difference Δn between the core and cladding is ~0.02 at 850 nm. The input and output waveguide facets are exposed with a dicing saw, and no post-processing steps are undertaken to improve the facet quality. The total waveguide length is 105.5 cm, while the waveguide design is optimised to achieve low bending and transition losses. Fig. 1(a) shows an image of the spiral waveguide illuminated with red light, while Fig. 1(b) shows the waveguide output facet illuminated with 850 nm light.

Experimental setup

The link setup employed in the data transmission experiments is shown in Fig. 2(a). An 850 nm VCSEL with a 9.5 µm oxide aperture (~25 GHz

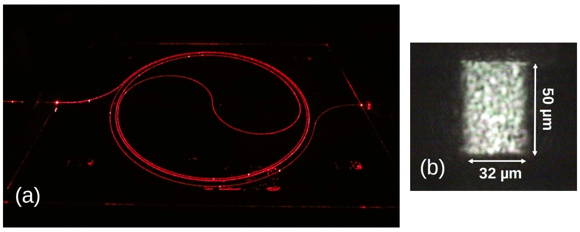

Fig. 1: Images of (a) the spiral waveguide illuminated with red light and (b) the waveguide output facet illuminated with 850 nm light.

bandwidth) is employed as the light source[5], while a 50/125 µm MMF pigtailed 30 GHz photodiode (VIS D30-850M) is used as the receiver. A pair of 16x microscope objectives (NA=0.32) is employed to couple directly the emitted light from the VCSEL into the waveguide and a cleaved 50/125 µm MMF patchcord is used at the waveguide output to collect the transmitted light. Index-matching gel is used at the waveguide output facet to minimise coupling losses. The received light is delivered to the high-bandwidth photodiode via a multimode variable optical attenuator (MM VOA, Agilent NA7766A) which is employed to adjust the average received optical power. A 2^7-1 pseudorandom bit sequence (PRBS), emulating the short run length block codes usually used in datacommunications, is generated by an Anritsu pattern generator (MP18000A) and directly modulates the VCSEL via a 40 GHz bias tee and a 40 GHz RF probe. The received electrical signals at the photodiode end are amplified by a 40 GHz SHF amplifier and delivered to a digital communication analyser (Infiniium 86100A) to observe the waveforms, and a bit-error-rate (BER) tester (Anritsu MP1800A) to perform BER measurements. For comparison, the corresponding back-to-back optical link (without the spiral waveguide) is also set up [Fig. 2(b)]. A cleaved 50/125 µm MMF collects the emitted light from the VCSEL source and another fibre patchcord delivers it to the photodiode via the MM VOA. The total insertion loss of the spiral waveguide [power difference between points A and B in Fig. 2(a)] is measured to be approximately 9 dB and includes the material, propagation and coupling losses. The insertion loss of the MM VOA is ~1.8 dB.

Data transmission results

The performance of both optical links (back-to-back link and the link with the 1 m long spiral waveguide) is assessed at the data rate of 25 Gb/s, 36 Gb/s and 40 Gb/s. The operating conditions of the VCSEL are appropriately adjusted for the different data rates in order to achieve optimum link performance. Typical values employed are ~14.6 mA bias current and ~1.2 Vpp RF modulation amplitude. Fig. 3 shows the received eye diagrams for the waveguide and the back-to-back link at all three data rates studied, while Fig. 4 shows the respective recorded BER curves. Open eye diagrams are obtained for the waveguide link for all studied data rates, while small additional noise and dispersion can be noticed in the waveforms due to the insertion of the waveguide in the link. The smaller eye opening observed for the higher data rates (36 Gb/s, 40 Gb/s) is due to the bandwidth limitation of the active components in the link and is also apparent in the eye diagrams obtained for the back-to-back link. Error-free (BER<10^{-12}) data transmission is confirmed with BER measurements up to 40 Gb/s. The BER curves demonstrate a small power penalty due to the insertion of the waveguide in the link. The power penalty for a 10^{-9} BER is found to be ~0.5 dB for 25 Gb/s, and ~1.2 dB for 36 Gb/s and 40 Gb/s. The results clearly demonstrate that the polymer multimode waveguide can successfully support high data rates, up to at least 40 Gb/s, despite its highly-multimoded nature and long length.

S_{21} measurement

To further demonstrate the adequate bandwidth of the 1 m long spiral waveguide, the frequency response of the back-to-back and waveguide link is recorded. A similar setup to that shown in Fig. 2 is employed, but the pattern generator and oscilloscope are replaced with a vector network analyzer. The frequency response of the waveguide is found by subtracting the two

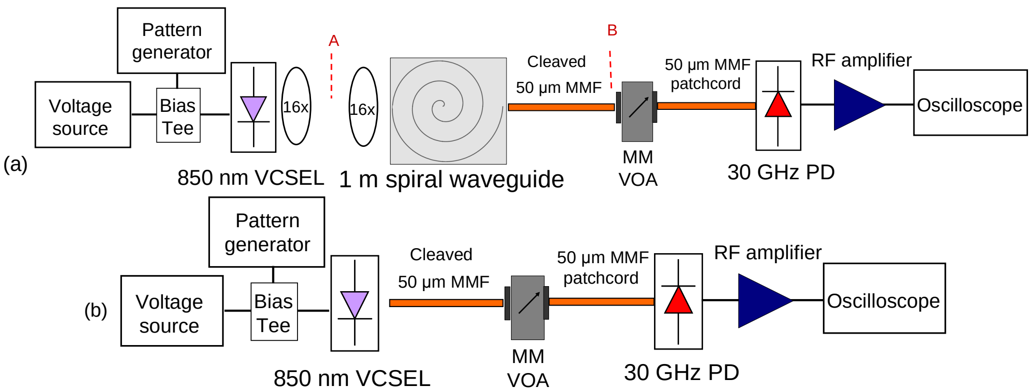

Fig. 2: Experimental setup for the (a) waveguide link and (b) the back-to-back optical link.

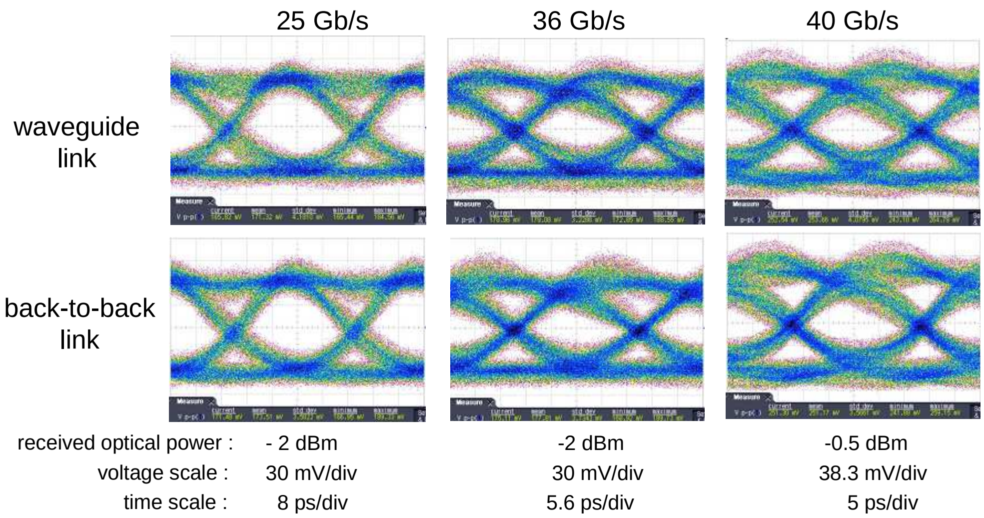

Fig. 3: Received eye diagrams for the waveguide and optical back-to-back link at 25 Gb/s, 36 Gb/s and 40 Gb/s. Average received optical power for each pair of eye diagrams, and respective time and voltage scales are also noted.

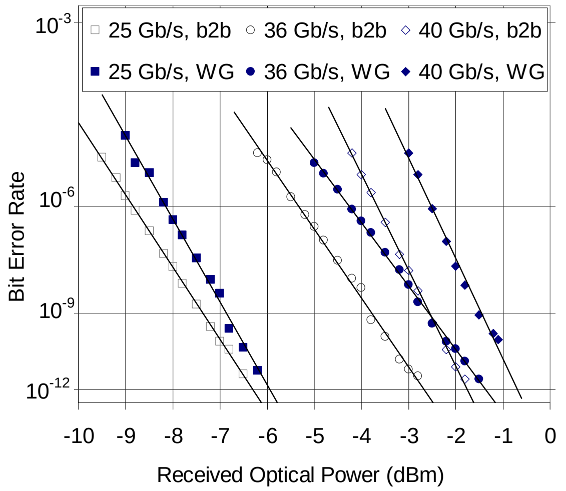

Fig. 4: BER curves for the optical back-to-back (b2b) link and the link with the 1 m long spiral waveguide (WG).

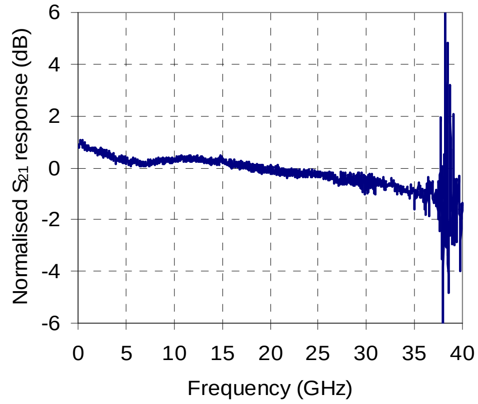

Fig. 5: Normalised frequency response for the 1 m long multimode spiral waveguide.

obtained log responses, and is plotted in Fig. 5. A relatively flat response is recorded for the waveguide up to at least 37 GHz, which constitutes the instrumentation limit for this measurement. The obtained frequency response further confirms the potential of such multimode waveguides to support data rates > 40 Gb/s over distances on the order of at least 1 m.

Conclusions

Multimode polymer waveguides constitute an attractive technology for use in high-speed board-level optical interconnects. Due to the highly-multimoded nature of these guides however, important questions about their potential to support data rates ≥ 25 Gb/s are raised. We report therefore in this paper record error-free data transmission up to 40 Gb/s over a 1 m long multimode polymer spiral waveguide and demonstrate that no significant transmission impairments in the link are observed. The results highlight the potential use of such long waveguides in high-speed board-level optical interconnects at data rates of 40 Gb/s and above.

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