Flexible Multimode Polymer Waveguides for High-Speed Optical Interconnects

Fengyuan SHI, Nikos BAMIEDAKIS, Richard V. PENTY, Ian H. WHITE, Daping CHU*

Electrical Engineering Division, Engineering Department, University of Cambridge,
9 JJ Thomson Avenue, Cambridge, CB3 0FA, United Kingdom
* dpc31@cam.ac.uk

Abstract: Flexible multimode polymer waveguides are shown to maintain bandwidth length products > 300 GHz×m for bend radii as low as 3 mm under restricted launch, with < 0.7 dB excess bend loss.

Introduction: Recently, multimode polymer waveguides have attracted increased interest for use in short-reach optical interconnections and optical backplanes. These waveguides can be formed and directly integrated on standard printed circuit boards (PCBs) owing to their favourable material properties [1]. Bandwidth studies have shown that the waveguides have the potential to support 100 Gb/s data transmission despite their highly-multimoded nature [1], and 40 Gb/s data transmission over a 1 m long multimode polymer waveguide has been demonstrated recently [2]. These waveguides can also be fabricated on flexible substrates enabling additional applications. Although studies on flexible multimode polymer waveguides have been reported [3, 4], there has been particular concern about the bend loss of waveguides required to provide high bandwidth. This work therefore reports the waveguide bend loss alongside bandwidth as a function of curvature and bending angle under restricted launch. The measured results indicate a bending and twisting loss of less than 0.7 dB for a curvature R > 3mm, despite allowing bandwidth-length products (BLP) of at least 300 GHz×m under restricted excitation. Further studies are underway combining loss and bandwidth measurements with near- and far-field measurements to reveal their mode loss and coupling behaviour and therefore, enable the design of optimised flexible waveguides and related components.

Bend loss measurement: The polymer waveguide samples are fabricated from siloxane materials [Dow Corning® OE-4140 (core) and OE-4141 (cladding) Cured Optical Elastomers] with a standard photolithographic method on flexible 125 μm-thick polyimide substrates. The waveguide cross section is ~50×50 μm^2 and samples of 10 and 24 cm in length are used for the measurements. An 850 nm vertical-cavity surface-emitting laser (VCSEL) is employed as the light source, while a cleaved fibre is used to couple the light. The waveguide sample is wrapped round a cylindrical mandrel and the output light is focused with a microscope objective onto a broad area detector (Fig. 1a). Mandrels with different diameters and different wrapping angles (from 0° to 180°) are employed. Moreover, the samples are twisted a variable number of turns and their insertion loss is recorded (Fig. 1b-d). Two different launch conditions are employed by using different types of cleaved fibres: a 4/125 μm single mode fibre (SMF) and a standard 50/125 μm multimode fibre (MMF), at the waveguide input in order to assess their loss performance under different types of excitation. For each launch condition and setup, 12 waveguides are measured and the average insertion loss value is obtained. The average insertion loss of the waveguide samples when not bent (R=∞) is also measured and used as a reference to obtain the excess bend loss. This is found to be 1.4 and 1.5 dB for the 10 cm-long samples under the SMF and 50 μm MMF inputs, respectively. Fig. 1e and 1f show the excess loss as a function of bending radius and angle (R = 5 mm), respectively, while Fig. 1g shows the excess loss when the sample is twisted (1 twist turn = 360°). The samples can be bent down to a radius of 2 mm without any cracks and with excess bend losses of below 1.5 and 3.7 dB for the SMF and 50 μm MMF inputs, respectively. The variation of bend loss with bending angle (Fig. 1f) indicates that the majority of the optical power is lost in the first 90° of the curvature. After that, lower order modes, which exhibit lower attenuation along the bend, are left to propagate in the waveguide. Twisting the samples more than 1 full turn (360°) however results in additional loss, mainly due to the acute twisting nodes (Fig. 1c) occurring in the flexible samples. Applying more than 2 turns, does not significantly further increase the loss as only the low order modes are left to propagate. Excess twisting losses of less than 0.6 and 2 dB are recorded for up to 4 full turns under the SMF and 50 μm MMF input, respectively. Similar bend loss performance is observed from the longer samples.

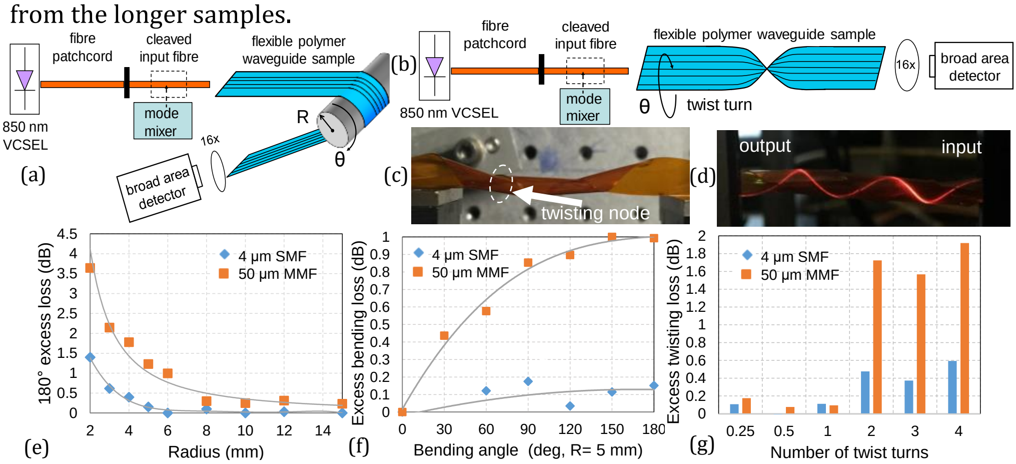

Fig. 1. Setup for (a) bending and (b) twisting loss measurements, images of (c) a twisted flexible waveguide sample (2 full twists) (d)with light, and excess bend loss as a function of (e) radius of curvature, (f) bending angle (R = 5 mm) and (g) number of full twist turns.

Bandwidth measurement: The bandwidth of the 24 cm-long waveguides is obtained using pulse broadening measurement. A setup similar to the one described in [1] is employed, while a 10× microscope objective with a numerical aperture (NA) of 0.2 is used at the waveguide input to emulate a SMF input. A short pulse (~400 fs FWHM) is launched into the flexed samples and the pulse broadening due to the waveguide dispersion is recorded for different bending radii. The waveguide BLP can then be extracted and it is found to be >300 GHz×m for all radii ≥ 3 mm under a restricted launch (Fig. 2). The results indicate that, under a restricted launch, tighter bends enhance mode coupling (rather than mode loss) in the waveguide and result in a slight reduction of bandwidth. This view can be confirmed by the increased NA of waveguides as measured (Fig. 2). Bandwidth measurements under different launch conditions are underway and the results will be presented at the conference.

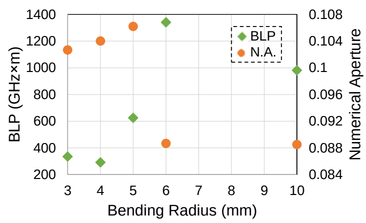

Fig. 2. BLP and NA as a function of bending radius

Conclusion: The loss and bandwidth of flexible multimode polymer waveguides are investigated under different launch conditions, providing an understanding of mode propagation in these waveguides. Excess bend and twisting losses as low as 0.7 and 0.6 dB, respectively, are demonstrated for radii greater than 3 mm while maintaining BLP of greater than 300 GHz×m under a restricted launch.

References

[1] J. Chen, et al., JLT, vol. 34, no. 12, pp. 2934–2940, 2015.
[2] N. Bamiedakis, et al., JLT, vol. 33, pp. 882-888, 2015.
[3] R. Dangel, et al., JLT, vol. 31, pp. 3915-3926, 2013.
[4] T. Chen, et al., JLT, vol. 33, pp. 2032-2037, 2015