Fan-in/Fan-out Three-dimensional Polymer Waveguide for Uncoupled Multi-core Fibers

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Abstract: Fabrication technologies and device performance of waveguide type fan-in/fan-out device for uncoupled multi-core fiber using Laminated Polymer Waveguide (LPW) are reviewed. The typical coupling loss from a 19-core fiber to nineteen single-core fibers was less than 2.0 dB and the sum of crosstalk from all neighboring cores was lower than -40 dB.

Introduction

Space division multiplexing (SDM)[1] using multi-core fibers (MCFs)[2] is the promising candidate for drastically increasing the transmission capacity. To realize an ultra-high capacity transmission system using the multi-core fiber, a compact integrated fan-in/fan-out device is required for the massive connection. Thus far, several fan-in/fan-out devices such as 3-d waveguide fabricated by ultra-short-pulse laser inscription,[3] tapered MCF connector,[4] thin-fiber bundle type fan-out,[5] grating coupler on Si waveguide[6] and lens coupling apparatus[7] have been reported. However, waveguide-type fan-out devices with mass-productivity, scalability for dense MCFs and the possibility of integration with other waveguide devices have not been reported.

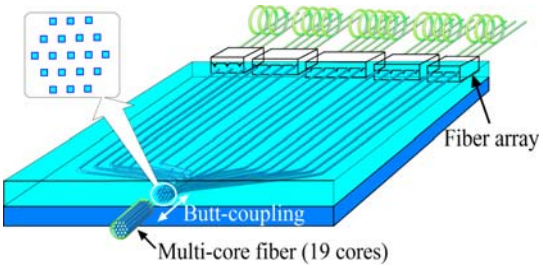


Fig. 1: Schematic view of LPW fan-out device.

In this review, fabrication technologies and device performance of 3-dimentional waveguide fan-in/fan-out device are introduced.

Fabrication

Figure 2 illustrates the fabrication process of the Laminated Polymer Waveguide (LPW). First, the bottom cladding layer is fabricated by the spin-coating and UV-curing of epoxy resin. The epoxy resin is a solvent-free oligomer supplied by NTT-AT. Since the oligomer does not shrink after UV curing, the top surface of the cladding layer can be flattened even if the bottom surface involves the core ridge as shown Fig. 2(c). Then, the core layer is fabricated by the spin-coating of PMMA solution. Here, a polyvinyl alcohol (PVA) layer and another resin layer are formed for the lift-off process. Next, the waveguide pattern is formed by photolithography using a silicone-based photo-resist (FH-SP3CL by Fujifilm) and RIE using O_2 gas. Finally, the mask layer is removed by the lift-off process using water. Then, these steps were repeated to form a multilayer waveguide.

Experimental results

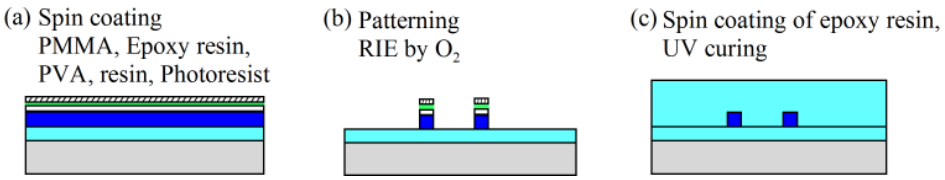
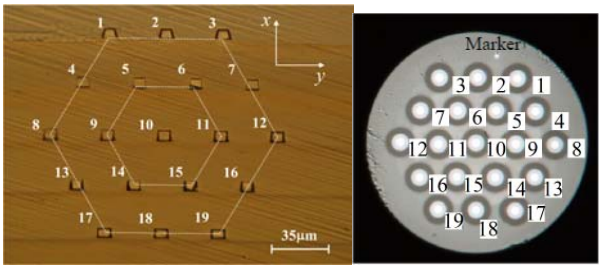


Fig. 2: Fabrication process of laminated polymer waveguide (LPW).

Figure 3(a) and (b) show the cross sectional microscopic images of the fabricated 19-core LPW fan-in/fan-out device and 19-core fiber[8] (supplied by Furukawa Electric Co., Ltd). The cores with the same number were butt-coupled. The core spacing of the multi-core fiber is 35.0 μm and the mode field diameter ranges from 9.56 to 9.85 μm.

First, to asses the coupling loss caused by the offset of core axis and spot sizes (half of MFD) mismatch, the offset loss characteristics were measured. Next, the spot sizes of respective cores of the LPW were evaluated from the measured offset loss characteristics[9]. Then, the spot size mismatch loss and the offset loss were calculated separately from the evaluated spot sizes. In addition, the index contrast Δ of the cores were evaluated by the spot sizes in *x* and *y* directions. The calculated results of the spot size mismatch loss, the offset loss and index contrast of 19 cores are summarized in Fig. 4. The coupling loss was as low as 0.2 - 1.8 dB from the fan-in device to 19-core MCF. The evaluated index contrasts were much smaller than designed value of 0.4%.



(a) LPW fan-in device (b) Multi-core fiber[8]

Fig. 3: Cross-sectional microscopic images

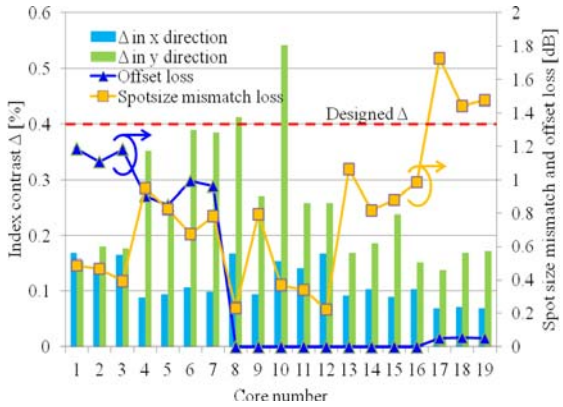


Fig. 4: Evaluated coupling losses and index contrast

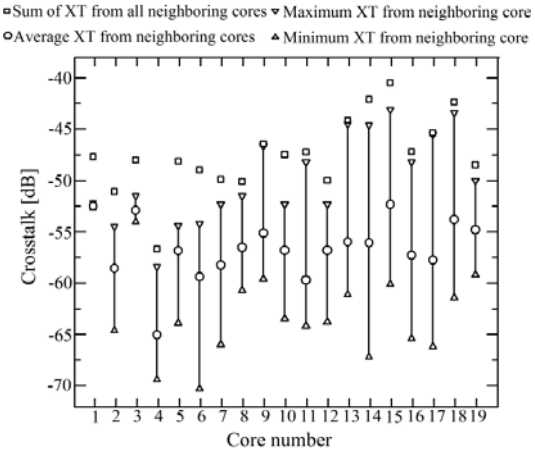


Fig. 5: Measured crosstalk of nineteen cores

Figure 5 shows the measured crosstalks of nineteen cores of fabricated LPW fan-in/fan-out device. In the worst case, the total crosstalk from 6 neighboring cores was less than -40 dB.

Conclusion

The fabrication technique of 3-dimensional multilayer waveguide is promising to not only the fan-in/fan-out devices but also mode multi/demultiplexers for mode division multiplexing. The fabrication error of index contrast will be improved by a careful investigation of UV curing condition and the synthesis process of oligomer material.

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References

1. T. Morioka, *OECC2009,* FT4 (2009).
2. M. Koshiba, K. Saitoh, Y. Kokubun *ELEX* **6**(2), pp. 98–103 (2009).
3. R. R. Thompson *et al*., *Opt. Express* **15**(18), pp. 11691-11697 (2007)
4. B. Zhu, *et al, Opt. Express* **18**(11), pp.11117-11122, (2010).
5. K. Watanabe, T. Saitoh, K. Imamura and M. Shiino, *OECC2012,* pp475-476 (2012)
6. C. R. Doerr *et al., Photon. Technol. Lett.* **29**(9), pp 597-599 (2011).
7. Y. Tottori *et al., Photon. Technol. Lett.* **24**(21), pp 1926-1928 (2012).
8. K. Imamura, *et al., IEEE Summer Top. Meet. Ser.*, pp 208-209 (2012).
9. T. Watanabe, M. Hikita and Y. Kokubun, *Opt. Express* **20**(24), pp 26317-26325 (2012).