Low-Loss 19 core Fan-in/Fan-out Device Using Reduced-Cladding Graded Index Fibers

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Abstract: We demonstrate a 19-core fan-in/fan-out device with low insertion loss using reduced-cladding graded index fibers and micro-structured preform. The average insertion loss for a pair of devices spliced to 3m of 19 core trench-assisted multicore fiber is 1.27 dB.

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1. Introduction

Space-division multiplexing (SDM) has been extensively investigated as a promising solution to increase the capacity of data transmission above the single-mode fibers (SMFs) limit. One of the approaches consists in the use of uncoupled multicore fibers (MCFs) [1]. MCFs offer the possibility to have different single-mode channels sharing a single cladding, thus increasing the amount of transmitted data by the number of cores present in the MCF, resulting in a practical single-fiber solution. MCFs with homogeneous cores can achieve higher transmission capacity without requiring advanced multiple input-multiple output (MIMO) receivers.

One of the challenges for uncoupled multicore fibers is the fabrication of fan-in/fan-out (FIFO) devices with low insertion loss and high core count that are required to couple to each individual core of the MCF. FIFO devices are not only needed for multicore fibers, they can also be used for coupled-core fibers [2] and coupled-core amplifiers [3]. Over the past few years, several types of FIFO devices with different number of cores have been proposed for single mode MCFs including fiber bundles [4, 5], 3D waveguides [6] and free space optics [7]. In this paper we discuss the fabrication of a 19-core FIFO device for single mode 19-core fiber using micro-structured preform and reduced-cladding graded index fiber. The device consists of 19 individual graded index fibers with 35 µm and 85 µm core and cladding diameter, respectively.

2. Fabrication of fan-in/fan-out device

One important characteristic to reduce the splice loss is to have similar MFD in both fibers to splice, additionally, in the case of MCFs the rotational alignment also plays an important role, as core misalignment can introduce additional coupling loss.

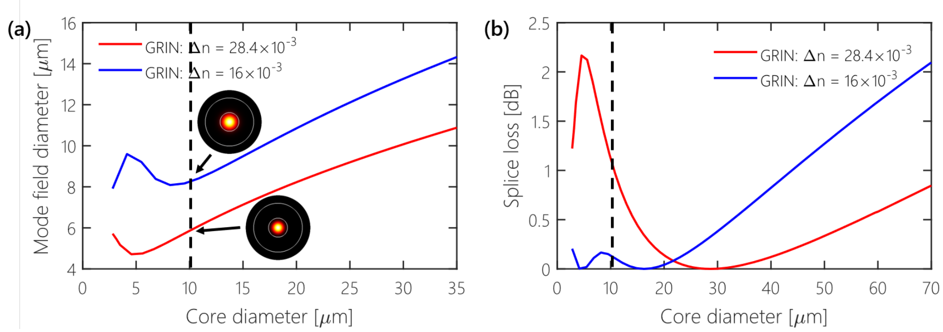

Fig. 1. Plots of a) Mode field diameter evolution for two graded index fibers with different index contrast of 28.4x10 $^{-3}$ and 16x10^{-3}, b) Calculated splice loss to the MCF fiber.

To reduce the splice loss we used a graded index fiber with a specific index contrast so that the mode field diameter before and after the taper matches that of a SMF and the MCF. This fiber is designed to keep the mode field diameter as close as possible to that of the MCF after tapering. Reduced-cladding fiber allows to decrease the taper ratio, increasing the adiabaticity requirements as less material is added before tapering, preventing the MFD in the fiber to change abruptly along the taper.

The FIFO device was fabricated with the goal to reduce the coupling loss to a trench-assisted MCF with a core-to-core distance of 35µm and a mode field diameter of 9.84 µm at 1550nm. We fabricated two fibers with the same core and cladding diameter but with different index contrast of $16\text{x}10^{-3}$ and $28.4\text{x}10^{-3}$, respectively. Figure 1a shows the mode field diameter (MFD) plotted as function of the core diameter for both fabricated fibers. From Fig. 1a we can observe that the MFD for the lower index contrast fiber decreases to about 8 µm when the core diameter is around 10 µm, whereas in the case of the fiber with higher index contrast, the MFD is decreased to about 6 µm when the core size is around 10 µm. Fig. 1b shows the splice loss to the MCF. It is important to notice that at the end of the tapered section, each graded index fiber reduces the core diameter to approximately 10µm. The splice loss is reduced for the case with the fiber with the lower index contrast, thus, for the fabrication of the actual device, graded index fiber with lower index contrast are preferable.

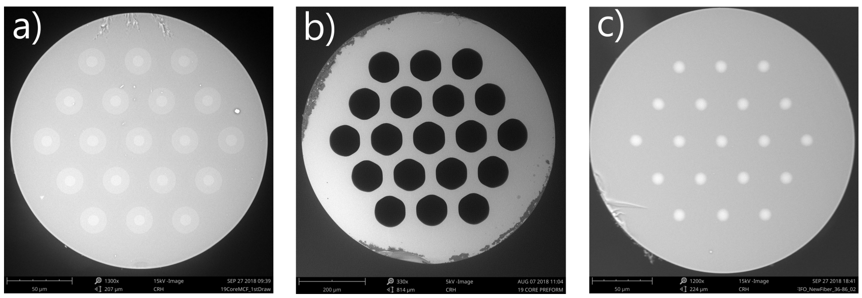

Fig. 2. SEM cross-section pictures of a) fabricated MCF, b) micro-structured preform used for the FIFO fabrication, and c) fabricated FIFO device.

To fabricate the fan-in/fan-out device 19 core individual fibers with a 35 µm and 85 µm core and cladding diameter, respectively, are inserted into the capillary shown in Fig. 2b. The capillary was fabricated using the stack and draw technique, and the diameter of the capillary is only 730 µm while each hole has a diameter of 90 µm. Using a CO_2-laser glass processor, the fiber bundled is down tapered by continuously heating and elongating the capillary. The taper ratio is set to about 3.4 in order to match the pitch of the multicore fiber as shown in Fig. 2a. In Fig. 2c we can report the cross section of the fabricated fan-in device showing the individual cores after tapering the capillary. Each core measures around 10 µm after tapering, and the theoretical MFD at this point is calculated to be 8.3 µm and the theoretical splice loss is only 0.2 dB to the MCF. The hexagonal array at the end of the taper matches precisely the core arrangement of the multicore fiber with only a small variation in the pitch of less than 0.5 µm. After the taper, the fundamental mode is still confined in each individual core, and low crosstalk is observed with the neighboring channels.

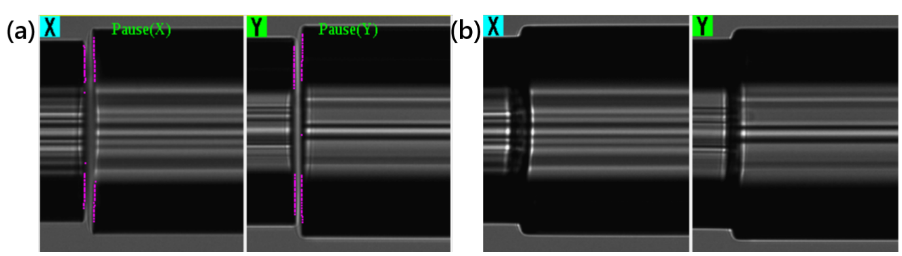

Fig. 3. a) cladding alignment of both fiber and FIFO, c) x and y view after the splice

Fig. 3 shows the alignment and splice of the multicore fiber and fan-in device using a CO_2-laser glass processor, one of the most important points when making the devices is to have the core to core distance to be the same as that of the multicore fiber, but is also very important the rotational alignment of the cores to have a good overlap between the cores, core misalignment due to rotational alignment and core pitch leads to increase on the splice loss. Another important parameter is the cleave angle in both, fiber and FIFO, the case shown in Fig. 3a shows cleave angles of 0.3 a 0.1 deg for fiber and FIFO respectively, having low cleave angles gives better performance during the splice as the end-facets are almost flat. The arc power used is lower compared to that required for a SMF splice but enough to joint them together, when using higher arc power the splice will look like a taper due to the difference in cladding diameters and it will cause to the cores in the outer ring to have a higher splice loss. In Fig. 3b, after the splice we still see the boundary of the fiber and FIFO showing that the cores in the outer ring will not have a high splice loss.

3. Characterization

After splicing two FIFO devices to 3m of the trench-assisted MCF, insertion loss was measured using a laser source centered at 1550 nm, exciting individual cores with a SMF and measuring the output power at the corresponding core using an optical power meter. The obtained average insertion loss for two FIFO devices is only 1.27 dB with insertion loss variation of 0.8 dB as shown in Fig. 4a, the lowest insertion loss obtained was 0.81dB and the biggest one of 1.62 dB for a pair of devices. To measure crosstalk, each individual core was excited and the power in the closest neighbors was measured. Fig. 4b shows the measured crosstalk, the blue triangles represent the highest crosstalk values and the red diamonds represent the lowest crosstalk value, in general and average crosstalk of <-20 dB is measured.

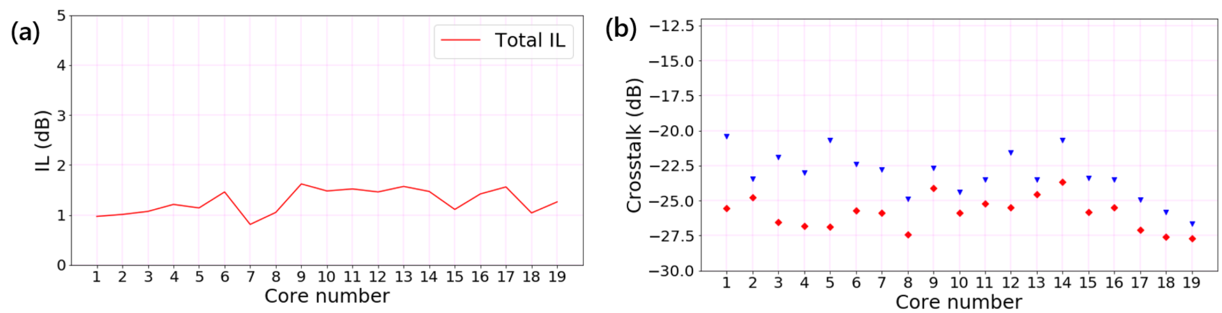

Fig. 4. a) Total insertion loss for a pair of FIFO devices spliced to 3 m of trench-assisted 19-core fiber. b) Measured crosstalk, black squares indicate the highest crosstalk value and the red dots indicate the lowest crosstalk value measured.

4. Conclusion

We have fabricated a 19 core FIFO device for a 19 core tench-assisted multicore fiber with average insertion loss of 1.27 dB for a pair of devices and crosstalk <-20 dB with the neighboring channels. The use of reduced-cladding graded index fibers allows to better match the MFD at the tapered side of the device as the MFD does not change much for low taper ratio, this technique can be applied to higher core count MCFs and can be improved by designing the graded index fiber with an specific index contrast to better match the specific MCF.

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