Novel Fuseless Optical Fiber Side-Coupler based on Half-Taper for Cladding Pumped EDFAs

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Abstract: We present a novel method for optical fiber side-coupler fabrication that does not require to heat the fibers. More than 94% of average coupling efficiency is demonstrated for input pump power ranging from 1.4 W to 20.7 W.
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1. Introduction

Over the next decade, space-division multiplexing (SDM) is expected to be a key technology to increase the capacity in communication networks [1]. For multicore erbium-doped fiber amplifiers (EDFAs) used in SDM networks, cladding pumping is usually preferred over core pumping since it allows using a single low-cost multimode laser diode (LD) as a pump source to amplify multiple cores. Cladding pumping is also beneficial in the case of multimode EDFAs as it leads to a more uniform overlap of the gain with the multiple modes, which thereby decreases the differential modal gain. Also note that cladding pumping of SDM EDFAs should ideally be performed by side-coupling since both the input and output fiber facets are usually used to couple the signal from the SDM transmission fiber to the doped core with as little loss as possible. In the past, several methods have been demonstrated to side-couple the output power of a LD into the fiber cladding; namely, embedded v-grooves (η=96%) [2] or mirrors (η=80%) [3], fused angle-polished fiber ($\eta\mu$=94%) [4], fusion of a multimode tapered fiber (η>96%) [5] and fuse-less optical-contact with a multimode tapered fiber (η=67%) [6] (η is the coupling efficiency). Because of their simplicity and their low cost, fused and fuse-less multimode tapered fibers are the most popular methods for SDM EDFAs. However, currently, the fuse-less method does not allow to reach high coupling efficiency, with the latest published results being below 70% [6]. With fusing a tapered fiber, the main issue is that heating of the doped fiber leads to distortion of the refractive index profile, resulting in increased loss and crosstalk between the modes [7, 8]. In this paper, we propose a simple and low-cost method, using a fuse-less multimode tapered fiber, and demonstrate more than 94% of coupling efficiency.

2. Description of the method

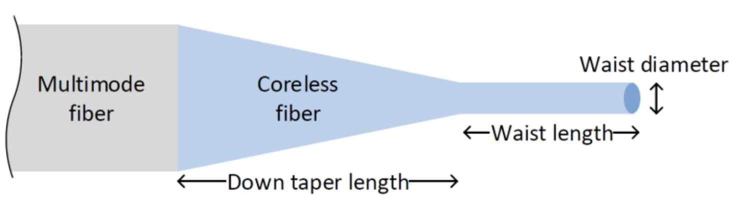

Fig. 1. Schematic of a half-taper.

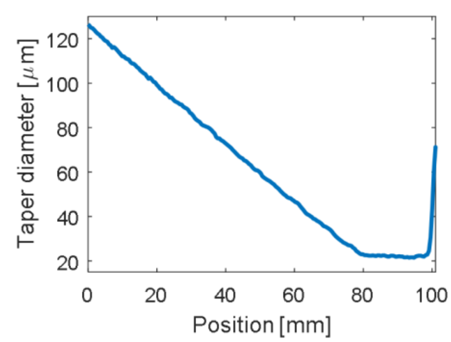

Fig 2. Taper profile measurement results.

In the proposed method, we first splice a multimode fiber with 105/125 μm of core/cladding diameter to a coreless fiber. We then use a CO_2 laser splicing system (Fujukura LZM-100) to taper the coreless fiber. Then, a blade is used to cut the coreless fiber at the end of the waist region in order to remove the up taper region. For the next steps, we therefore only keep the half-taper shown on Fig. 1. The multimode fiber is spliced to the output fiber of a 978-nm multimode high power laser diode (the pump source). The receiving fiber, used to quantify the coupling efficiency, is a 125 μm coreless fiber coated with a low-index polymer of the same type that is used in double-clad fiber (n=1.33) to insure that the pump power is guided in the cladding. The polymer coating of this receiving fiber is mechanically removed over 12 cm to allow optical contact with the half-taper. Finally, the half-taper is put in close proximity to the uncoated region of the receiving fiber and droplets (1-2) of isopropyl alcohol are applied over the whole half-taper. The half taper than spontaneously rolls around the receiving fiber, thanks to surface tension. Even after the liquid has completely dried, the half-taper sticks to the receiving fiber and the coupling efficiency remains stable.

3. Couplers characterization

For power efficiency measurement, 13 distinct half-tapers were fabricated with various geometries and a camera was used to measure their tapering profile. An example of a taper profile measurement, before removing the up taper, is shown in Fig. 2. Prior to the experiments, the power delivered by the 978-nm pump laser was calibrated by measuring it directly at the output of the multimode fiber for 20 different driving current set points corresponding to an output power range from 1.4 W to 20.7 W. The setup for coupling efficiency measurements is shown in Fig. 3. A 1 m length of receiving fiber was used and an index matching gel was applied over 4 cm on its unused end (left) in order to eject the power out of the fiber and minimize the impact of reflections on the power measurements. A picture of the region where the coreless fiber and the double-cladding fiber are in optical contact is shown in Fig. 4.

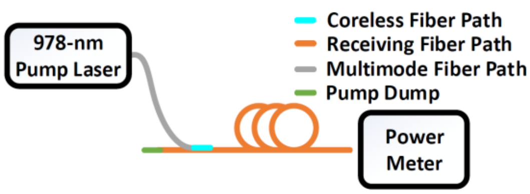

Fig. 3. Setup used for the characterization of the couplers.

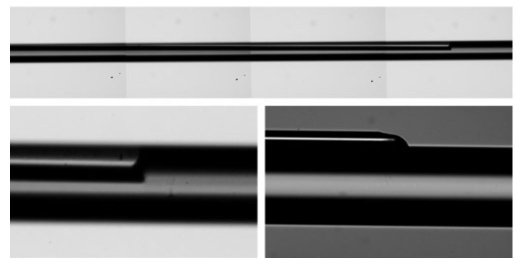

Fig. 4. Photos of a part of the region where the coreless fiber and the double-cladding fiber are in optical contact.

The coupling efficiency was calculated by assuming that all of the power injected into the fiber reaches the power meter without any loss, i.e. it is simply calculated by dividing the measured output power for a given current set point by the power delivered by the 978-nm pump laser for this same set point. Using the method described above, each of the 13 half-tapers was installed on the receiving fiber and their coupling efficiency was measured with the 20 calibrated current set points. The two tapers that gave the best results (#5 and #13) were later re-used for 2 additional experiments, which consisted in using the same method to install the half-taper but adding a low index polymer (n=1.33) over the whole region on which the half-taper and the double-cladding fiber are in optical contact. The details of the taper geometries, as well as the average coupling efficiency over the 20 pump power measurements are shown in Table. 1.

Table 1. Taper geometry and average coupling efficiency results for the 15 half-taper samples

Experiment #	Downtaper length [cm]	Waist length [cm]	Waist diameter [μm]	Low index polymer?	Average coupling efficiency [%]
1	4.5	4.0	44	No	80
2	4.5	4.0	28	No	77
3	4.5	4.0	15	No	81
4	9.0	1.0	15	No	86
5	7.0	1.0	15	No	88
6	5.0	1.0	15	No	76
7	9.0	1.0	28	No	87
8	7.0	1.0	28	No	82
9	5.0	1.0	28	No	82
10	9.0	1.0	44	No	78
11	7.0	1.0	44	No	66
12	5.0	1.0	44	No	71
13	8.0	2.0	22	No	92
14	7.0	1.0	15	Yes	94
15	8.0	2.0	22	Yes	95

Considering the limited amount of data, it was not possible to identify optimized values for all parameters. However, by comparing results of experiments #5 vs #14 and #13 vs #15, we see that the use of an overlay of low index polymer over the optical contact region, clearly allows increasing the coupling efficiency. We also noticed that removing the half-taper from the receiving fiber and replacing it back later, using the same method, always led to coupling efficiency variations of less than 2% from the previous measurements, indicating that the method is very repeatable. Another trend that can be identified is that the coupling efficiency increases on average by 4% when the power delivered by the 978-nm pump laser is increased from 1.4 W to 20.7 W. This coupling efficiency increase is shown on Fig. 5 and could be related to thermal effects increasing the optical contact between the half-taper and the double-cladding fiber. Finally, a coupling efficiency stability test was conducted over one hour and is shown on Fig. 6. We also cycled the coupled pump power and did not observe any hysteresis.

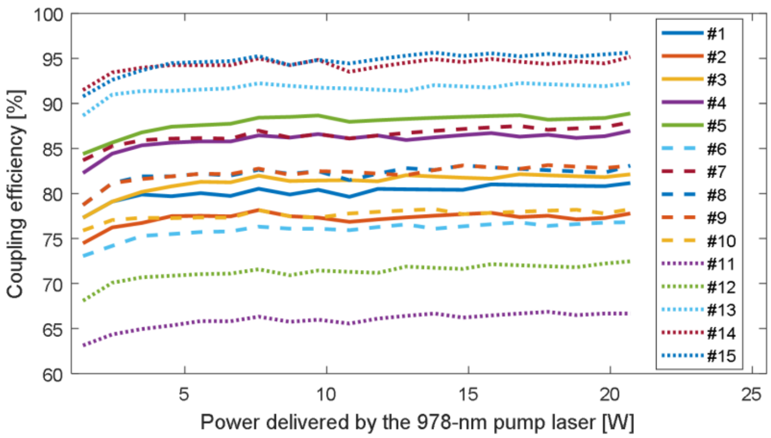

Fig. 5. Coupling efficiency as a function of power delivered by the 978 nm pump laser for all of the experiments.

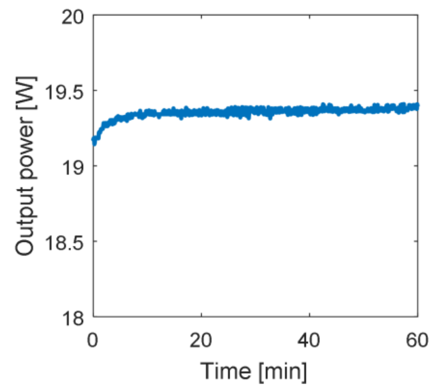

Fig. 6. Stability of the side-coupler over time

4. Conclusion

We propose a novel low-cost and easy to use coupling method to inject high pump power (1.4 W to 20.7 W) in double cladding EDFAs with high efficiency (>94%). This method offers the advantage of not requiring to apply any heat on the receiving fiber, which is a clear benefit for SDM EDFAs where slight geometry distortion can lead to crosstalk between the guided modes and deterioration of the signals.

5. References

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