OPTICAL PROPERTIES IMPROVEMENTS OF N-MDFS BY COMBINING TWO NOVEL NEGATIVE DISPERSION FIBERS

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Abstract: By dividing N-MDF into two parts and applying a restrict mode excitation method, we successfully enlarged the Aeff of N-MDF. The equivalent Aeff of MDF which consists of P-MDF and N-MDF could be successfully enlarged and the optical characteristics of the transmission line were drastically improved.

1 INTRODUCTION

Dispersion management lines (DMLs) which consist of positive and negative dispersion fibers are very attractive transmission lines because they can suppress the total dispersion close to zero in the wide telecommunication band. SLA + IDF is one typical example of DMLs and their high transmission performances in the 10 Gb/s transmission system have been reported [1]. MDFs (Medial Dispersion Fibers) are a type of dispersion management transmission lines which is suitable for the high capacity submarine transmission system over 40 Gb/s and the high transmission performances of MDFs have also been reported [2]. The typical properties of MDF are shown in Table 1. To increase the transmission capacity, some trials have been performed [3-5]. About P-MDF (Positive-MDF), Aeff enlargement by the Ring-core profiles [4,5] or the attenuation reduction by applying F-Clad technology [5] have been reported. On the other hand, the Aeff of the conventional N-MDF (Negative-MDF) has been restricted to about 32 □m2. This time, we investigated about the possibility of enlarging Aeff of N-MDFs utilizing two methods; one is dividing N-MDF into two parts which consists of the large Aeff fiber and large dispersion fiber, and another is adopting a multi mode design while keeping single mode transmission. From these points of views, we carefully designed and fabricated the fibers and successfully improve the optical properties of N-MDF.

Fiber type		P-MDF	N-MDF	Total
Dispersion	[ps/nm/km]	13	-13	0
Disp. slope	[ps/nm^2/km]	0.07	-0.07	0
Aeff	[μm^2]	95	32	63*
Attenuation	[dB/km]	0.19	0.22	0.205

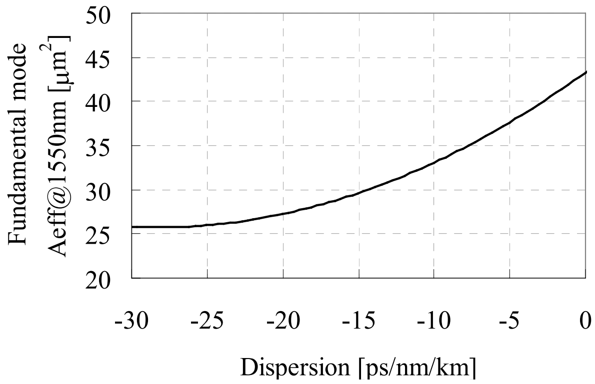
(*)Equivalent Aeff with span length of 50km

Table 1 Typical properties of MDF

2 IMPROVEMENT OF THE PROPERTIES OF N-MDF BY DIVIDING N-MDF INTO TWO PARTS

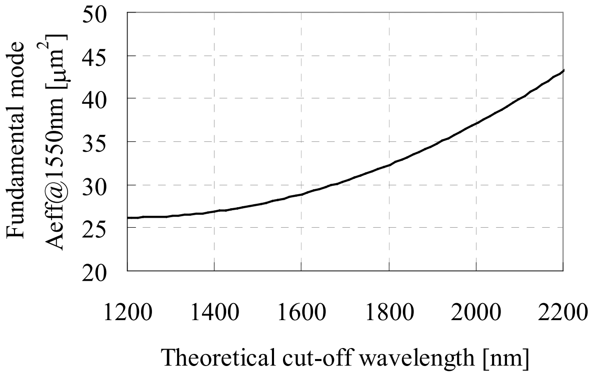
MDFs are a type of dispersion management transmission lines which consists of P-MDF and N-MDF in a same length ratio. MDFs are suitable for the high capacity submarine transmission system because of the suppressed accumulated dispersion. P-MDFs which have large Aeff are placed after the EDFAs in order to suppress the non-linear effect and N-MDFs are placed in the latter part to compensate the dispersion and dispersion slope of P-MDF. While, because the Aeff of N-MDF is relatively small, the nonlinear effect occurred in N-MDF would be of concern.

By the way, the Aeff of N-MDFs tends to increase as the dispersion become larger (smaller absolute dispersion) as shown in Fig. 1. So, by dividing N-MDF into two parts which consist of a small dispersion fiber (Fiber A) in the former part and a large dispersion fiber (Fiber B) in the latter part, a nonlinearity of N-MDF could be improved efficiently. On the other hand, trade-off relations are always exist within the properties of any types of N-MDFs. However, it is possible to enlarge Aeff keeping similar dispersion and bend characteristics by shifting the cut-off wavelength to the longer wavelength (Fig. 2). So, we have tried to improve the Aeff of Fiber A (the small-dispersion large-Aeff fiber) by shifting the cut-off wavelength to the longer wavelength.



(DPS = 185 nm, Theoretical cut-off wavelength = 1800 nm)

Fig. 1 Relation between dispersion and Aeff



(Dispersion = -13 ps/nm/km, DPS = 185 nm)

Fig. 2 Relation between cut-off wavelength and Aeff

The higher order modes propagate through the fiber when the cut-off wavelength shifts to the longer wavelength. However, in case of N-MDF which is always placed after the front single mode fiber, only the fundamental mode can be selectively excited because the light is inputted around the center of the core. We call this phenomenon "Restrict Mode Excitation". Fig. 3 is the field distribution of the fundamental mode (LP01) and the higher order modes (LP02, LP11, LP21) of Fiber A. In these figures, the colored region indicates the field distribution of conventional SMFs. The field distributions of the LP11 and the LP21 are existed outside the core, so the excitation efficiencies of these modes likely to be extremely low when the light is inputted around the center of the core. On the other hand, the LP02 has a field distribution having two peaks, namely center peak and side peak. However, the numerically studies about the coupling efficiencies from the SMF to the LP01 and the LP02 (Fig. 4) showed that the coupling efficiency to the LP02 is negligible value, -14 dB. This fact indicated that it is possible to excite only the LP01 selectively by connecting the single mode fiber in front of newly-designed cut-off shifted N-MDF.

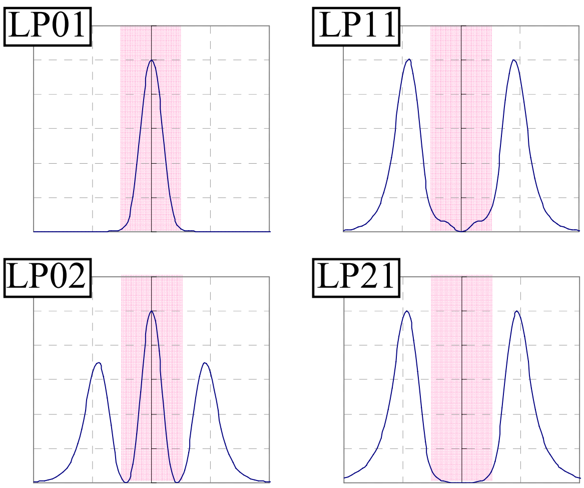


Fig. 3 Field distributions of each mode in Fiber A

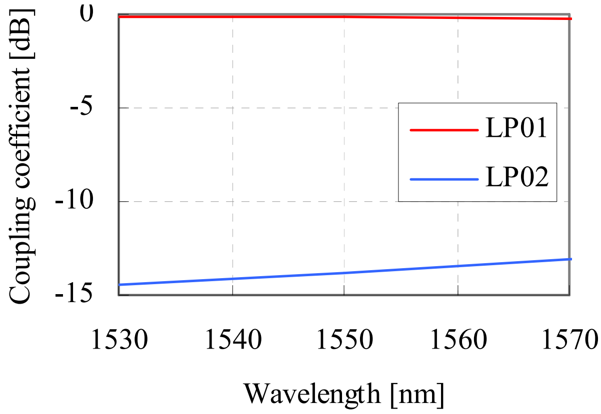


Fig. 4 Coupling efficiencies to the LP01 and the LP02

Based on the concept explained above, we actually fabricated Fiber A and B. We fabricated the small dispersion fiber with multi mode design (Fiber A) as the former part, and the large dispersion fiber (Fiber B) as the latter part. As shown in Table 2, the Aeff of N-MDF could be successfully enlarged keeping other properties as conventional. The equivalent Aeff of a 50 km-span transmission line combined with P-MDF could also be enlarged to 70.3 □m2. As confirmed by these investigations, the restrict mode excitation method can provide the capability of improving the non-linearity drastically, that is indispensable for the high capacity transmission.

Fiber type		Fiber A	Fiber B	N-MDF 1*	Total
Length ratio		0.57	0.43		
Dispersion	[ps/nm/km]	-4.1	-24.7	-13	0
Disp. slope	[ps/nm^2/km]	-0.04	-0.11	-0.07	0.00
Aeff	[μm^2]	47.2	30.5	40.8**	70.3***
Attenuation	[dB/km]	0.226	0.227	0.226	0.208

*) Optical properties of Fiber A + Fiber B

**) Equivalent Aeff with 25km N-MDF

***) Equivalent Aeff with span length of 50km

Table 2 Properties of fabricated fiber and total transmission line

3 IMPROVEMENT CONCERNING ABOUT LENGTH RATIO

Since N-MDF consists of two types of fibers, the equivalent Aeff can be further enlarged by optimizing the length ratio of the two fiber pairs as well as improving each non-linear property. Therefore, we tried to improve the large dispersion fiber which is combined with Fiber A in terms of dispersion and non-linear properties by means of restrict mode excitation method (Fiber C). The dispersion was set to the value near the target, -13 ps/nm/km, to increase the length ratio. The properties of Fiber C itself, N-MDF which consists of Fiber C and Fiber A, and the total transmission line that consists of P-MDF + N-MDF (FiberC + FiberA) are shown in Table 3 respectively. Because the Aeff of Fiber C was enlarged over 50 □m2 by shifting the cut-off wavelength to the longer wavelength, and because the length ratio of Fiber C occupied about 71 % of N-MDF, the equivalent Aeff of N-MDF could be enlarged as 53.1 □m2 and that of total transmission line as 75.5 □m2 which is large improvement from conventional MDFs. The attenuation loss was a relatively high, but it should be reduced as low as Fiber A and B by the fabrication process optimization.

Even though the Aeff of Fiber C has successfully enlarged, it forced to shift the cut-off wavelength longer than fiber A. So, the coupling efficiency to the LP02 becomes large, inevitably. The coupling efficiencies of the LP01 and the LP02 calculated from the measured refractive index profile of the Fiber C are shown in Fig. 5. An issue which needed to be carefully taken into account was the propagation of the higher order modes in the Fiber C due to the higher coupling efficiency to the LP02 mode compared to the Fiber A. We carried out the pulse propagation experiments in order to confirm whether the distortion of pulse shape due to the higher order modes' propagation could be observed or not using the experimental setup shown in Fig. 6. The pulse train with the 300 MHz repetition rate, which was generated by DFB-LD and signal generator, was inputted to 10 m and 3,500 m of Fiber C after the SMF and the output pulse was analyzed by a sampling oscilloscope. Under the bad coupling condition between SMF and Fiber C, the distortion of the pulse shape which indicates the existence of the higher order modes was observed. However, under the good coupling condition, no pulse distortion was observed (Fig. 7). Note a clean signal could be obtained for the 3,500 m Fiber C as well. Though the optimization of the splice conditions are still reminded as an issue need to be addressed, the properties of the total transmission line was successfully improved by utilizing the restrict mode excitation.

Fiber type	Fiber C	Fiber A	N-MDF 2*	Total
Length ratio	0.71	0.29		
Dispersion [ps/nm/km]	-16.7	-4.1	-13	0
Disp. slope [ps/nm^2/km]	-0.07	-0.04	-0.06	0.00
Aeff [μm^2]	52.6	47.2	53.1**	75.5***
Attenuation [dB/km]	0.288	0.226	0.270	0.230

*) Optical properties of Fiber C + Fiber A

**) Equivalent Aeff with 25km N-MDF

***) Equivalent Aeff with span length of 50km

Table 3 Properties of the fabricated fiber and transmission line

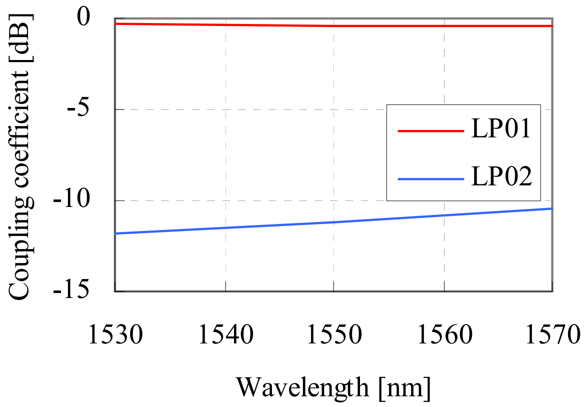


Fig. 5 Coupling efficiency of LP01 and LP02

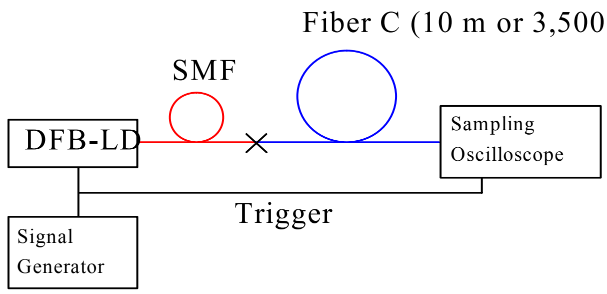


Fig. 6 Experimental setup of Pulse experiment

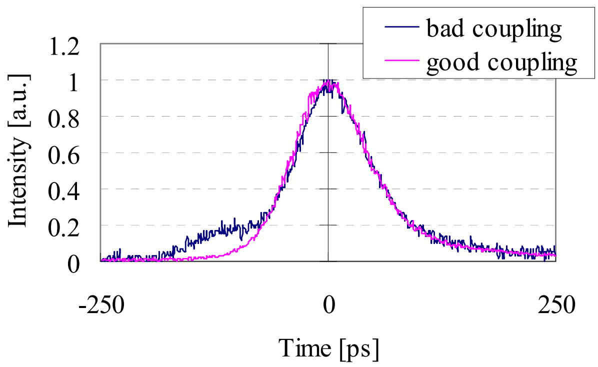


Fig. 7 Pulse experimentation result

4 CONCLUSION

By dividing N-MDF into two parts and applying a restrict mode excitation method, we successfully enlarged the Aeff of N-MDF. The equivalent Aeff of MDF which consists of P-MDF and N-MDF could be successfully enlarged and the optical characteristics of the transmission line were drastically improved.

5 REFERENCES

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