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Reverse dispersion fiber with depressed core-index profile for dispersion-managed fiber pairs

Xiaoqiang Jiang [a], Ruichun Wang [b,*]

[a] Opto-Electronics Engineering Department, Huazhong University of Science and Technology, Wuhan City 430074, PR China
[b] Yangtze Optical Fiber and Cable Company Ltd., Fiber Department, No. 4, Guanshan Road, Wuhan City 430074, PR China

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Abstract

A reverse dispersion fiber (RDF) with depressed core-index profile has been developed successfully by using plasma chemical vapor deposition (PCVD) process. The fabricated RDF has a core-effective-area of 45 μm^2, a dispersion of -19.65 ps/nm/km and a dispersion slope of -0.132 ps/nm^2/km while maintaining the low bending induced attenuation and low PMD value. The dispersion-managed pairs, which consisted of RDF and non-zero dispersion shifted fiber with ultra large effective core-area (ULAF), have the ultra low dispersion slope of less than 0.006 ps/nm^2/km at the wavelength range of 1530–1625 nm, and the largest dispersion value is lower than 0.2 ps/nm/km. Moreover, the attenuation characteristic also shows a remarkable flatness over the broadband wavelength, the attenuation at 1550 nm is only 0.224 dB/km. The dispersion-managed pairs are suitable for large capacity, high bit-rate long-haul wavelength division multiplexing (WDM) transmission system without using dispersion compensation mode.

Keywords: Reverse dispersion fiber; Wavelength division multiplexing; Dispersion; Dispersion compensation module; Polarization mode dispersion; Splice loss

1. Introduction

With the application of high capacity wavelength division multiplexing (WDM) long-haul transmission system with large channel counts (≧40 channels) and high bit rate channel speeds (≧10 Gb/s) to meet the explosive increasing demand for bandwidth, dispersion and nonlinearity have been become the limiting factor, and the link dispersion tolerance is decreasing exponentially with the increase in the channel bit rate [1,2]. In order to decrease the residual link dispersion, dispersion management technique is designed to decrease the link-average dispersion by periodic alternation of

* Corresponding author. Tel.: +86 27 8780 2541 dial 5111; fax: +86 27 8742 4548.
E-mail address: wangruichun@yofc.com (R. Wang).

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the dispersion [3]. Using the dispersion compensation module (DCM) containing a dispersion compensation fiber (DCF) with reverse dispersion and equal relative dispersion slope (RDS), the ratio of dispersion slope to dispersion, to that of the transmission fiber is the primary technology [4]. However, DCF has some potential problem such as increasing the nonlinearity, polarization mode dispersion (PMD) and transmission loss due to their small effective area ($\leqslant 20\ \mu m^2$) and extremely high relative refractive index difference (delta value).

Recently, a hybrid fiber transmission line as a form of dispersion-managed fiber technology has been proposed [5–7], dispersion and dispersion slope can be managed within the dispersion matched pairs span containing a positive dispersion fiber with large effective area and a reverse dispersion fiber (RDF). This hybrid solution can not only offer substantially less first-installed cost as well as simplified terminal station complexity by reducing the number of modules required, but also reduce the transmission loss, nonlinearity and PMD due to the relative large effective area and low delta value of RDF as compared with that of DCF. Moreover, hybrid fiber transmission lines also can provide a further benefit, since both positive and negative dispersion slope fibers are exposed to the same environment and both can see the same temperature variations and contribute opposite signs of dispersion variations.

In this work, we designed a RDF with depressed core-index profile by using low pressure plasma chemical vapor deposition (PCVD) process, the fiber with this profile can achieve a large A_{eff} of $45\ \mu m^2$, which is much larger than that of the RDF with conventional W-shaped profile structure as reported ($25–36\ \mu m^2$) [7–9]. A dispersion-managed fiber pairs with low loss, low nonlinearity, low PMD and almost entirely flatness dispersion slope can be constructed by connecting this RDF to the ultra large area fiber (ULAF) we have fabricated [10,11].

2. RDF design

A basic design criterion of RDF in hybrid fiber transmission lines is that the product of absolute residual dispersion times the square of the bit rate must be less than some limit. To expand the transmission distance and increase the transmission bit rate for the WDM system specially, it is necessary to manage the dispersion accurately in the transmission line, and the parameters of dispersion slope compensation ratio are therefore great important. Dispersion slope compensation ratio R is defined by Eq. (1):

$$R\ (\%) = \frac{S_{\mathrm{RDF}}}{S_{\mathrm{ULAF}}} \Big/ \frac{D_{\mathrm{RDF}}}{D_{\mathrm{ULAF}}} \cdot 100 = \frac{RDS_{\mathrm{RDF}}}{RDS_{\mathrm{ULAF}}} \cdot 100, \tag{1}$$

where D_{RDF}, S_{RDF}, RDS_{RDF} are dispersion, dispersion slope and relative dispersion slope of RDF, respectively, D_{ULAF}, S_{ULAF}, RDS_{ULAF} are dispersion, dispersion slope and relative dispersion slope of ULAF, respectively. RDS is defined as the ratio of dispersion slope to dispersion. The closer the dispersion slope compensation ratio R is to 100%, the less the residual dispersion in the dispersion-managed links is over a broadband wavelength. Another important design tradeoff is between effective core-area and dispersion. In general high negative dispersion means that high refractive index and narrow core region are required. However, high refractive index will result in small effective core-area and also relative high attenuation [8]. The small effective core-area, as we know, may bring some potential problems such as nonlinearity especially in the high bit rate transmission system. The RDF with conventional W-shape refractive index profile usually has a relative small effective core-area of about $25–32\ \mu m^2$. In order to increase the effective core-area, in this work, a refractive index profile with depressed center core was adopted. According to the experience of development ULAF and other reports [10–12], we know that the fiber with depressed center core profile can usually achieve a large effective core-area. On the other hand, based on the recent study, a hybrid fiber transmission lines with an ULAF to RDF length ratio of 2:1 were found to perform well for the DWDM transmission system [13], the absolute dispersion value of RDF is therefore designed to be two times that of ULAF.