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DESIGN OF DISPERSION COMPENSATING FIBERS WITH HIGH NEGATIVE DISPERSION, LOW BENDING AND SPLICE LOSSES: A COMPARATIVE ANALYSIS

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Abstract— *In optical communication system different types of fibers are laboring for different application. Loss and dispersion are two essential parameters to be determined as low as possible while designing optical fibers as optical transmission lines. The dispersion of optical pulses procreation in high speed WDM optical transmission systems is almost imminent. For acceptable compensation of the dispersion compensating fiber (DCF) is one of the approaches of attaining a high negative dispersion is to modify the refractive index profile of DCFs. In this paper, by using optifiber software, the shifting of the zero dispersion wavelength(ZDW) is made by changing the refractive index profiles of a standard single mode fiber(S-SMF), then the designed profile is promote for low dispersion, bending loss and splice loss. The attained result show that in designed profile the effective mode field diameter is diminished, which can adequately reduced the splice loss. In another observation, the parameter of peculiar DCF profiles are optimized to enhance negative dispersion of about -879 ps/nm. km with splice loss of 9. 9dB/km and bending loss 0. 52 dB/km at bending radius of 20 mm is obtained.*

Keywords— *Refractive index profile, Negative Dispersion, Macrobending loss, Dispersion compensating fibers.*

1. INTRODUCTION

As the number of users are increasing every year, the demand for data rate and required channel capacity are also increasing. Optical communication fulfils this increased demand through its excellent transmission characteristics such as enormous bandwidth and low loss.

The optimal design and application of optical fiber are very vital to the transmission quality of optical fiber transmission system. And the major goal of communication system is to increase the transmittal distance. Loss and dispersion are the major factor that affect fiber-optical communication being the high-capacity develops.

Unshifted single mode fibers (USMF) have minimum dispersion in 1300 nm optical window, while at 1550 nm window the dispersion is at highest level and the attenuation is at lowest value. Meanwhile, for longest transmission distance, the dispersion and the attenuation should be at minimum values. To achieve this condition, one has to shift the minimum dispersion of 1300 nm window in to the 1550 nm window. One of the approaches is to reduce considerably the diameter of a USMF so as to develop a dispersion shifted fiber (DSF). On the other hand, the reduction of diameter can cause nonlinear phenomenon of four wave mixing (FWM) at 1550 nm. To nullify this effect, the zero dispersion should be shifted to some other wavelengths in the 1550 nm region.

Since 1990, different types of DCFs have been designed and developed with commercial qualities, and till date the designers are puting efforts to maximize the negative dispersion values of the DCFs. In recent years, photonic crystal fibers (PCF) have attracted the attention of designers of optical devices to develop high negative dispersion compensating fiber (DCF) to be used in long haul high bit rate optical transmission system.

First, by manipulating the profile, the ZDW is shifted to another wavelength within third optical communication window. Then, by using Optifiber software, the profile is optimized for reduction of positive dispersion and splice losses. To manage the dispersion of the transmission fiber, the parameters of refractive index profile effective area of a single mode fiber are optimized to enhance the nagative dispersion, while keeping the macrobending loss at low level.

2. DISPERSION AND MACROBENDING LOSS

Dispersion is defined as because of the different frequency or mode of light pulse in fiber transmits at different rates, so that these frequency components or model receive the terminals at different time. It can cause in tolerable amounts of distortions that ultimately lead to errors[5]. As a pulse of light propagates through a fiber, elements such as numerical aperture, core diameter, refractive index profile, wavelength and laser line width cause the pulse to broaden. Dispersion increases along the fiber length[5].

Generally, dispersion in optical fiber is determined by the following expression[3],

$$D = \frac{-2\pi c}{\lambda^2}\frac{d^2\beta}{d\omega^2} \qquad (1)$$

Where λ the optical wavelength, C speed of light in a vacuum, ω angular optical wavelength and β is the propagation constant. The second derivation of propagation constant with respect to angular optical frequency is given by[3],

$$\frac{d^2\beta}{d\omega^2} = \frac{1}{c}\left(2\frac{dn_{eff}}{d\omega} + \omega\frac{d^2 n_{eff}}{d\omega^2}\right) \qquad (2)$$

Where $n_{eff} = \Delta n_{eff} + n_{clad}$ the effective core refractive index, n_{clad} refractive index of cladding, Δn_{eff} is the relative refractive index difference between core and cladding and $\beta = k_0 n_{eff}$, and k_0 is the wave number in a vacuum.

The total dispersion, due to material and waveguide dispersion is obtained as[3]:

$$D = \frac{-2\pi c}{\lambda^2}\left[\frac{d^2 k_0 \Delta n_{eff}}{d\omega^2} + \frac{d^2 k_0 n_{clad}}{d\omega^2}\right] \qquad (4)$$

Dispersion of the transmission fiber should be fully compensated by using dispersion compensating fiber.

When diameter of the trench is increased, the overlap between core and ring modes is decreased and curvature of the effective index difference is increased resulting in a very negative dispersion[2].

The performance of a dispersion compensating fiber module over a wide wavelength range can be evaluated using the residual dispersion, which is the dispersion measured after the dispersion compensating fiber module in the receiver[2].

The total residual dispersion D_{res} is [2],

$$D_{res} = D_{TF} L_{TF} + D_{DCF} L_{DCF} \qquad (5)$$

If zero dispersion is desired after the dispersion compensating fiber module in the receiver, the length of the dispersion compensating fiber(L_{DCF}) is given as[2],

$$L_{DCF} = -\frac{D_{TF}}{D_{DCF}} L_{TF} \qquad (6)$$

The macro bend losses can be reduced by increasing the effective index[2].

The macrobending loss in terms of attenuation coefficient γ is defines in dB/km as [3]:

$$\alpha_{maro} = \frac{10}{L}\log\left(\frac{p_{in}}{p_{out}}\right) = \frac{10}{L}\log[\exp(\gamma L)] = 4.35\gamma \qquad (7)$$

Where L is the length of transmission line in km, P_{in} is the input power and P_{out} indicated the output power at the end of transmission lines.

3. DESIGN OF DCF'S

Conventional single-mode fibers in C-band of optical communication have positive dispersion of about 18ps/nm. km. The more transmission distance, higher will be the dispersion effects on the transmitted pulses. To neutralize this phenomenon, design of dispersion compensating fiber (DCF) with negative dispersion[3]. To achieve a high negative dispersion in DCFs with high effective core area and a low macrobending loss, it is required that parameters of the refractive index profile be suitably changed in such a way to ensure the single-mode operation of the fiber[4].

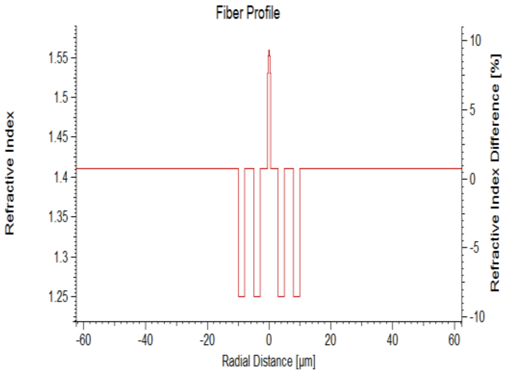
In this section three types of profile geometries, namely, Gaussian, exponential, parabolic index are suggested for DCFs. The commercial optifiber software is employed in all our design procedure[11].

3. 1 Gaussian double ring index profile

A Gaussian function is used to design a DCF RI as depicted in fig. 1 is designed using the following index profile model [8].

$$n_{Gaussian}(r) = \begin{cases} n_{\max} & |r| = 0 \\ n_0(r) = n_{\max}.\exp\left\{-\ln 2.\left[\frac{2.(r-r_0)}{h.w}\right]^2\right\} & 0 < |r| \le R_0 \\ n_1 = const & R_0 < |r| \le 62.5\mu m \end{cases} \qquad (8)$$

where r_0 is the peak position, Nmax is the maximum refractive index of that region, and h is normolized value of full width half maximum.

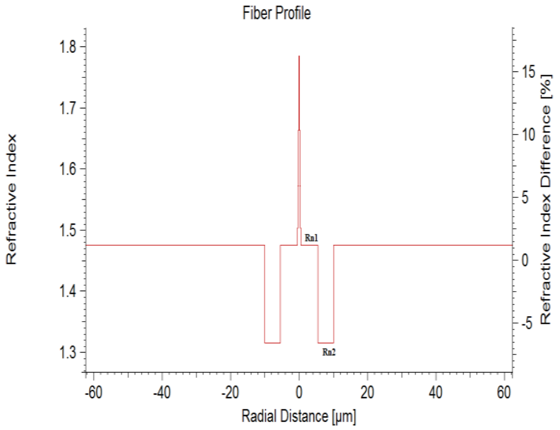


Figure(1). Gaussian double ring index profile of DCF

3. 2 Exponential index profile

By using the same parameters and employing the following index model, we obtain a exponential index as show below,

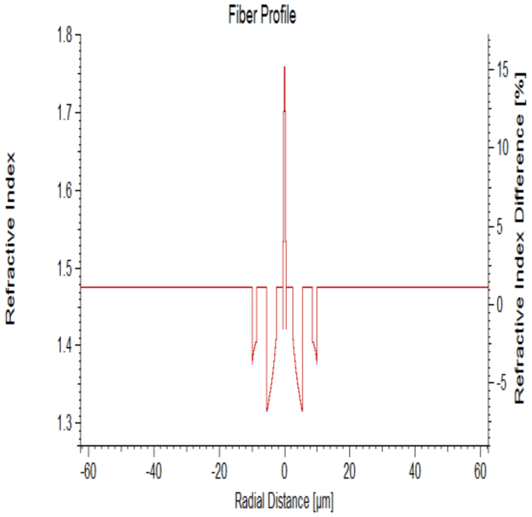
$$n(x) = [n(0) - n(w)]\frac{e}{e-1}\exp(-x|w) + \frac{e.n(w)-n(0)}{e-1}$$



Figure(2). Exponential index profile of DCF

3. 3 Parabolic double index profile

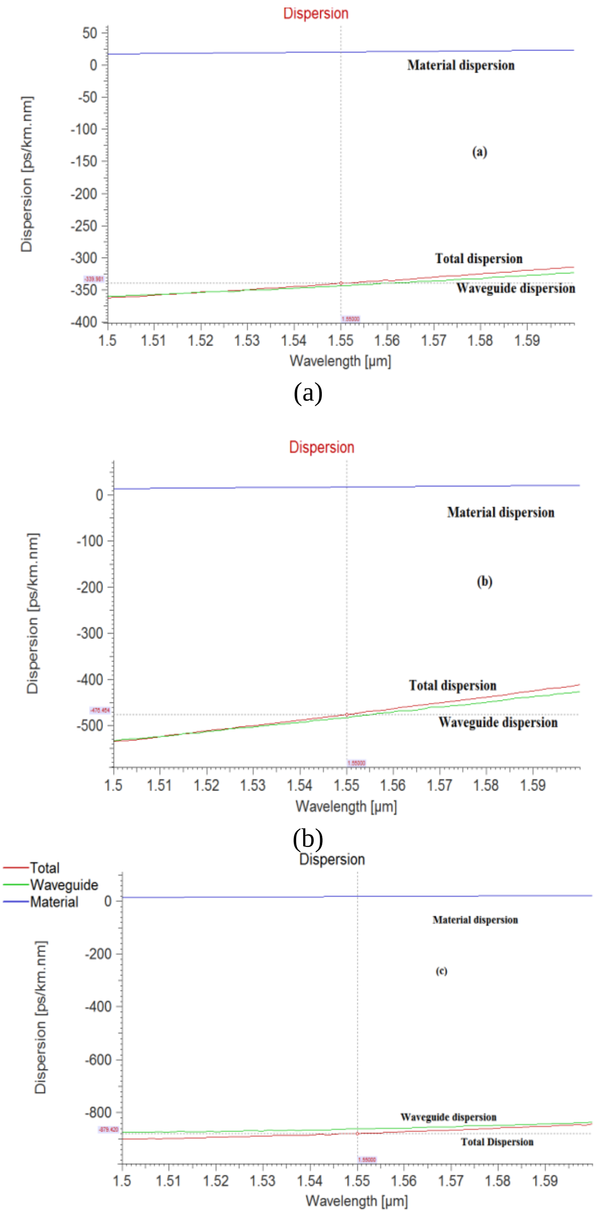
In this case, in relation with the Δ variations, the ring regions in parabolic index profile are more effective than other two cases. Conceptually one can note that the ring regions in parabolic index profiles could help this effectiveness in negative dispersion.



Figure(3). Parabolic double index profile of DCF

Table 1. Comparison of designed parameters of optimized DCF profiles with reported ref. [4] and [3]

Parameter profile	Index region(μm)						Bending loss (dB/km)	splice loss (dB)	Total Dispersion (ps/nm.km)	PMD (ps/km)
Gaussian double index	1	5	4	6	4	105	1.634	38.7	-339	6.18
Exponential index	1	10	9	105	-	-	0.487	19.33	-476	16.03
Parabolic double index	1	4	4	6	4	106	0.52	9.9	-879	10.4
Parabolic index	1.1	2	7	6	108.9	-	0.002	10.9	-646	6.18
Ref[[4]	4	4	6	6	105	-	0.42	41.22	-	12.76
Ref[3]	-	-	-	-	-	-	3.3	-	-517	-



(a)

(b)

(c)

Figure (4). Dispersion of the designed DCFs (a)gaussian double index (b)exponential index (c)parabolic double index.

3. 4 comparison of the DCF Designs

To obtain maximum negative dispersion with minimum macrobending loss. All proposed profiles have the different double-core index with different dimensions. The ratio of regions layers R_{n2}/R_{n1} is increased with increment of 0. 8. In

Ref [3], step index with two ring index profile was proposed and the reported negative dispersion at 1550nm wavelength was -517ps/nm. km. In our design procedures, three types profiles of gaussian, exponential, parabolic index.

In Fig. 4, the respective dispersions are plotted as a function of wavelength. In gaussian double index profile, the negative dispersion was enhanced to -339 ps/nm/km. For case of exponential, parabolic profile, even more negative dispersion have achieved, i.e., -476 and -646 ps/nm. km, respectively, where in each case, waveguide, material and total dispersion are depicted.
In Table1, all the designed parameters, such as bending loss, splice loss, total dispersion, polarization mode dispersion(PMD) are tabulated and compared with reported result [3] and [4] at 1550nm wavelength. The final results show that the highest negative dispersion and low bending loss is achieved via parabolic index profile.

4. Conclusion

In this paper, we have analyzed three refractive index profiles for optimization of high negative dispersion compensating fibers with low bending loss and splice losses. The length of DCF fiber also reduced.
A comparison of results of the analyses of different refractive index profiles of proposed DCFs show that highest negative dispersion, namely -879 ps/nm. km, is achieved in parabolic double index profile. splice loss of 9. 9dB/km and bending loss 0. 52 dB/km at bending radius 20 mm is achieved via parabolic double index profile.

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