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Designing a Highly Nonlinear Normally Dispersive Optical Fiber for Efficient Parabolic Pulse Generation

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ABSTRACT

A highly nonlinear silica based multi-cladded step index dispersion compensating fiber (HN-DCF) is designed in such a way that it possesses a very small effective area when compared with standard silica based fibers. It is seen that when input Gaussian pulses are passed through the proposed fiber, perfect parabolic similaritons are generated at smaller optimum length even in the presence of higher order dispersion and nonlinearity. Therefore the proposed fiber can be treated as best choice for parabolic pulse generation with less input power requirement in comparison to standard normal dispersion fibers.

Keywords: Highly nonlinear dispersion compensating fiber, Nonlinear Schrödinger equation, Parabolic self-similar pulse, Effective area.

1. Introduction

Self-similar parabolic pulses [1] are drawing significant research interests due to their strictly linear chirp and find potential applications in the area of high power femtosecond lasers [2], supercontinuum generation [3], pulse reshaping [4] and many more. The deleterious effect of optical wave breaking that critically degrades the system performance can be avoided by using the parabolic pulse as input one. This type of pulses propagates in a self-similar manner by conserving certain relationship among energy, pulse width and frequency chirp. They are analogous to the well-known Solitons. Linearly chirped parabolic pulses are self-similar solutions of the nonlinear Schrödinger equation (NLSE) with gain [5]. The required gain can be provided by using fiber amplifiers [6] and dispersion decreasing fibers (DDFs) [7]. As nonlinearity and dispersion both play important role in the context of parabolic pulse propagation, highly nonlinear fibers (HNLFs) are becoming a burning research topic. While a pulse propagates through a fiber, several unavoidable nonlinear phenomena like self-phase modulation (SPM) [5], cross-phase modulation (XPM) [5] and four-wave mixing (FWM) [5] arise. Fiber nonlinearities can be constructively used in fiber lasers like Raman fiber lasers, Brillouin fiber lasers and parametric oscillators. A new type of HNLF design with good field-confinement along with lower dispersion fluctuations was proposed by Kuo *et al.* [8]. This type of fibers represents high nonlinearity as well as low attenuation, splicing and bending losses and has potential to be implemented as an all-fiber wavelength converter by four-wave mixing. In the present work, a silica based normally dispersive highly nonlinear dispersion compensating fiber (HN-DCF) has been designed and optimized. A Gaussian pulse is employed as input pulse in this fiber and the reshaping of the pulse towards parabolic pulse is observed.

2. Design and Optimization of Normally Dispersive Highly Nonlinear Dispersion Compensating Fiber

A B_2O_3 and Na_2O doped silica core, F doped silica inner cladding and GeO_2 doped silica outer cladding are chosen to design a step index normally dispersive highly nonlinear dispersion compensating fiber, with relative refractive index difference (Δ) of 0.041 and depression depth parameter (ρ) 1.079 at the operating wavelength of 1.55μm. The refractive index profile is shown in Fig. 1.

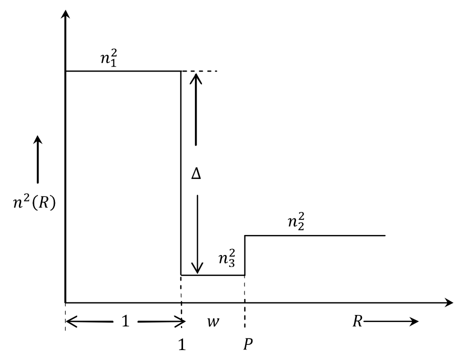


Figure 1: Refractive index profile of a centrally step index multi-cladded fiber

Here $R = r/a$, r being the radial coordinate from the center and a is the core radius of the fiber. Here n_1 and n_3 represent the maximum refractive index at the step index central core ($0 \leq R \leq 1$), the depressed cladding ($1 < R \leq P$) respectively and n_2 is the refractive index of the outer cladding. The relative width (w) of the depressed cladding is (P-1).

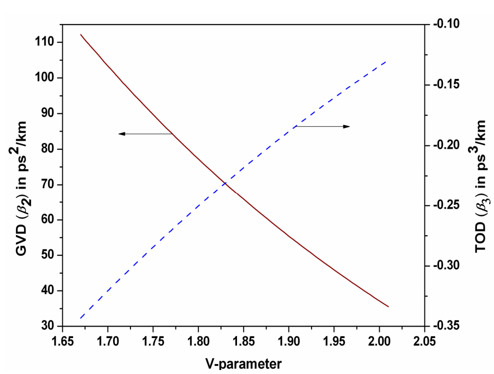


Figure 2: Variation of GVD and TOD factors with V-parameter

According to the objective, the proposed fiber is designed by optimizing the inner clad width *w* and *V*-parameter to achieve the lowest value of the effective area (A_{eff}). The obtained value of the effective area of the proposed fiber is much lower when compared to standard silica based fibers [9]. When V-parameter is changed from 1.67 to 2.01, the group velocity dispersion (GVD) decreases from 112.18 ps^2/km to 35.52 ps^2/km whereas the third order dispersion (TOD) substantially reduces from -0.34 ps^3/km to -0.13 ps^3/km. These graphical natures of GVD and TOD are illustrated in Fig. 2 by brown solid curve and blue dash curve respectively.

The nonlinear coefficient (γ) of our proposed normally dispersive fiber with B_2O_3 doped silica glass core is estimated to be very high ~ 24.76 $W^{-1}km^{-1}$. Therefore a normally dispersive silica based highly nonlinear fiber (HN-DCF) is designed and optimized.

3. Performance of the proposed HN-DCF in Similariton Generation

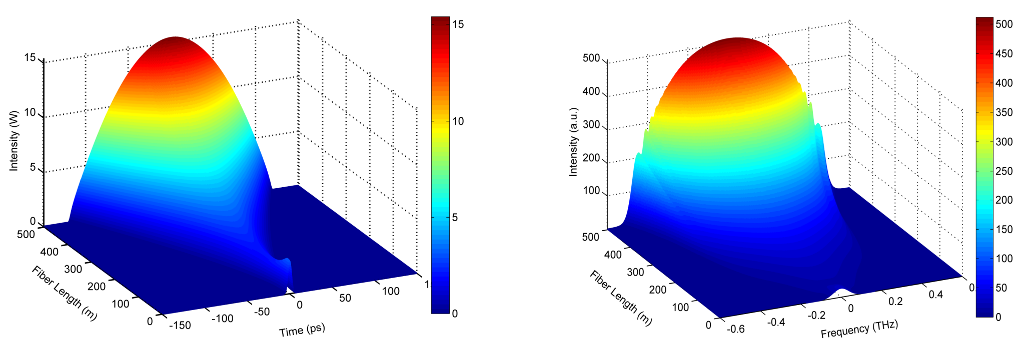
The pulse propagation through normally dispersive fiber, can be described by the nonlinear Schrödinger equation (NLSE) with gain as below [5],

$$i\frac{\partial A}{\partial z} = \frac{\beta_2}{2}\frac{\partial^2 A}{\partial T^2} + \frac{i\beta_3}{6}\frac{\partial^3 A}{\partial T^3} - \gamma|A|^2 A + i\frac{(g-\alpha)}{2}A, \qquad (1)$$

where $A(z,T)$ is the slowly varying envelope of the pulse, β_2 is the group velocity dispersion (GVD) factor and γ is the nonlinear coefficient for the fiber. In presence of third order dispersion (TOD) the second term in right hand side of (1) also plays an important role. Here, α is the fiber loss, T is the time in co-propagating frame, z is the distance of propagation and (g- α) is the gain over loss.

The evolutions of a 3W input Gaussian pulse through the proposed HN-DCF towards parabolic self-similar regime in temporal and spectral domains are depicted in Fig. 3(a) and Fig. 3(b) respectively.

It is found that the proposed HN-DCF is much more advance for parabolic pulse generation at smaller optimum lengths as well as the output peak power is much smaller in comparison to standard DCFs. It will also perform better for supercontinuum generation than standard DCFs due to larger spectral broadening.



(a) (b)

Figure 3: Evolution of an input Gaussian pulse through HN-DCF towards parabolic self-similar regime in (a) temporal and (b) spectral domains

4. Conclusion

A multi-cladded normally dispersive highly nonlinear dispersion compensating fiber (HN-DCF) is designed and optimized at the operating wavelength of 1550 nm in such a way that the nonlinear coefficient (γ) is estimated to be much higher (~ 24.76 W-1km-1) with high values of GVD (β2) ~ 99.43 ps2/km, TOD (β3) ~ -0.31 ps3/km. A Gaussian pulse is sent at the input of our proposed HN-DCF and its evolution towards parabolic shape is observed. The proposed HN-DCF is much more advance for parabolic pulse generation at smaller optimum lengths which proves that the proposed HN-DCF is the favorable selection for generation of parabolic similaritons.

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