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A Novel Optical Soliton Compression Method Based on Step-Like Nonlinearity Profiled Fiber

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Abstract: A novel optical soliton compression technique based on step-like nonlinearity profiled fiber is proposed. The step-like nonlinearity profiled fiber is composed of single mode fiber (SMF), dispersion-shifted fiber (DSF) and high nonlinear fiber (HNLF). All the components used in the simulation are available in reality. Compared with other soliton compression techniques, this method is easy to control and its cost is low also. It is shown in numerical simulation that a hyperbolic secant pulse, whose width is 12. 5 ps and peak power is 300mW, can be compressed to a 1. 28 ps-width, 1. 3 W-peak power pulse by using this step-like nonlinearity profiled fiber transmission line.

Key words: Nonlinear optics; Optical pulse compression; Solitons; High nonlinear fiber

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0 Introduction

The development of ultra-short pulses is significant for many applications, such as ultrafast phenomena, optical metrology, and high-speed optical communication. Pulse compression is a well-known technique to obtain such short pulse. There are three main methods for pulse compression: high-order soliton compression, self-phase modulation in a normally dispersive medium followed by dispersion compensation, and adiabatic soliton compression (ASC)[1]. The first method is highly sensitive to the noise of input pulses. It requires high input power and the compressed pulse has a pedestal. The second method uses a conventional SMF for dispersion compensation of a highly amplified optical pulse, and the fiber nonlinearity could drastically deteriorate the waveform of the pulse. The last method uses dispersion-decreasing fiber in which soliton energy is maintained and pulse duration decreases as dispersion, or uses a fiber Raman amplifier in which pulse duration decreases as soliton energy increases because of Raman gain. It gives high-quality pulses, but the resulting energy gains are small. And the DDF length or amplifier length must increase exponentially with the input pulse duration to satisfy the adiabatic condition. The principle of adiabatic soliton compression is fundamental soliton that can maintain its properties undistorted because of the combind effects of group velocity dispersion (GVD) and self-phase modulation (SPM).

At present, dispersion-decreasing fiber (DDF)[2], nonlinearity increasing fiber and distributed raman amplification are used to realize various types of ASC. The current research work based on nonlinearity increasing fiber is limited to the theoretical simulation because of the nonlinearity increaing fiber is difficult to manufacture[3]. We used step-like nonlinearity profiled fiber consisting of single mode fiber (SMF), dispersion-shifted fiber (DSF) and high nonlinear fiber (HNLF). This structure could be achieved in practice. Compared with other adiabatic soliton compression based on Raman amplification or DDF, this method is easy to control and its cost is low also. The adiabatic soliton compression scheme needs the parameters vary gently, and in the pure numerical simulation scheme, the parameters could be selected properly to comply the adiabatic condition. But in practice, the parameters of fiber can't be various gently[4]. So in fact, the step-like nonlinearity profiled fiber scheme we proposed (for the parametric selection is closer to reality) can't comply the adiabatic condition. The ASC scheme performs gentle and high-quality optical pulse compression. In contrast, our scheme offers steep and low quaility compression (entails a large pedestal)[5]. The pedestal energy ratio is taken into account in our

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simulation.

1 Theoretical basis

The pulse compression process in fiber is governed by the nonlinear Schrödinger (NLS) equation. For a standard single-mode fiber, it exhibits anomalous group velocity dispersion (GVD) at 1 550 nm wavelength, and the NLS equation can be written as[1]

$$\mathrm{i}\,\frac{\partial U(\xi,\tau)}{\partial \xi}+\frac{1}{2}\,\frac{\partial^2 U(\xi,\tau)}{\partial \tau^2}+ N^2\exp(-\alpha L_{\mathrm{D}}\xi)\,|U(\xi,\tau)|^2 U(\xi,\tau)=0 \quad (1)$$

where $U(\xi,\tau)=A\mathrm{e}^{-\alpha z}/\sqrt{P_0}$ is the normalized amplitude, $\xi=z/L_{\mathrm{D}}$ is the normalized distance, $\tau=T/T_0$ is the normalized time, α accounts for fiber loss, and the parameter N^2 is given by

$$N^2=\frac{L_{\mathrm{D}}}{L_{\mathrm{NL}}}=\frac{\gamma P_0 T_0^2}{|\beta_2|} \quad (2)$$

In equation (2), P_0 is the input peak power , T_0 is the input pulse duration, γ is the nonlinear parameter, and β_2 is GVD parameter. The length scales L_{D} and L_{NL} are the dispersion length and the nonlinear length, respectively. They are defined as

$$L_{\mathrm{D}}=\frac{T_0^2}{|\beta_2|} \quad L_{\mathrm{NL}}=\frac{1}{\gamma P_0} \quad (3)$$

In order to scale the quality of the compressed pulses, we defined a compression factor F_c, pedestal energy ratio R, they are given by

$$F_c=\frac{T_0(0)}{T_0(\xi)} \quad R=\frac{|E_{\mathrm{total}}-E_{\mathrm{sech}}|}{E_{\mathrm{total}}} \quad (4)$$

where $T_0(0)$, $T_0(\xi)$ are the FWHM (Full Width at Half Maximum) of input and output pulse, E_{total}, E_{sech} are the total pulse energy and fundamental soliton pulse energy, respectively.

The high nonlinearity fiber (HNLF) performs a key device in the compressor, which has the nonlinear coefficient (γ) the times larger than the normal SMF. γ is defined as

$$\gamma=n_2\omega_0/cA_{\mathrm{eff}} \quad (5)$$

where n_2 is the Kerr coefficient and A_{eff} is the effective area. A standard SMF has the SiO_2-based core with a small amount of GeO_2 as a dopant, and n_2 is estimated to be $2.6\times10^{-20}\ \mathrm{m^2/W}$. The n_2 of SiO_2-based core could be increased by doping GeO_2 in a high concentration, and it has been shown that a conventional HNLF has n_2 of $4-5\times10^{-20}\ \mathrm{m^2/W}$. And the HNLF has a extremely small effective area. The HNLF we used in simulation has only $A_{\mathrm{eff}}=12.7\times10^{-12}\ \mathrm{m^2}$, as a contrast the SMF has $A_{\mathrm{eff}}=80\times10^{-12}\ \mathrm{m^2}$.

In this paper, we report a novel compressor consisting of ordinary single mofe fiber (SMF), dispersion-shifted fiber (DSF) and high nonlinear fiber (HNLF) to achieve the quasi-nonliearity increasing. The structure is shown in Fig. 1, and the parameters of fibers are shown in Table 1. Compared to the comb-like profiled fiber, the step-like profiled fiber has the model of simple structure (only three segment fibers), doesn′t require precious control of fiber length[6-9]. In our simulation, the soliton source generates a hyperbolic secant pulse with its central wavelength, width and peak power is 1 550 nm, 12.5 ps and 300 mW, respectively, which consistent with the fundamental soliton condition ($N=1$). And the compression factor is tunable by changing the gain of EDFA and the length of fibers.

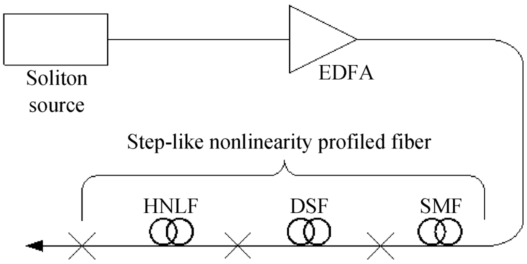


Fig. 1 The structure of experimental setup

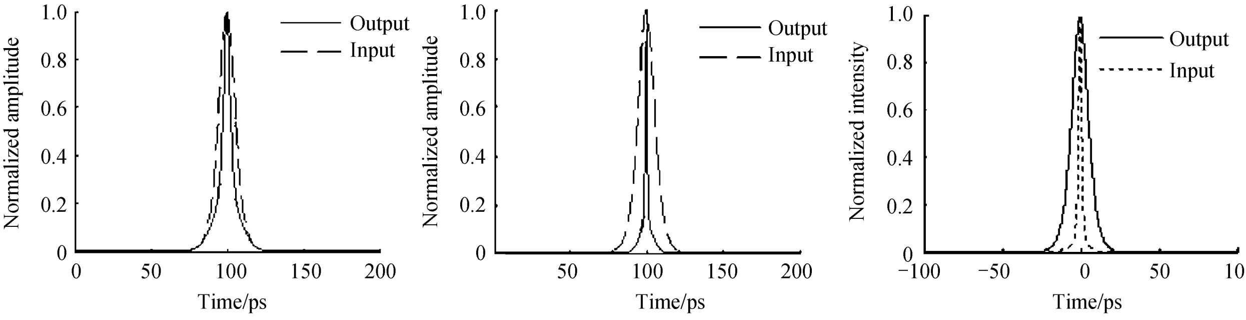
Table. 1 Parameters of fibers

	α/ (dB·km^{-1})	D/ (ps·nm·km^{-1})	γ/ (W^{-1}km^{-1})	L/ km
SMF	0.2	17	1.314	6
DSF	0.25	4.286	2.685	6
HNLF	1.244	1.658	11.44	1.6

2 Results and discussion

The first two segments of the compressor are consisted of SMF and DSF(Scheme 1), which are the basic unit of the comb-like profiled fiber. This section plays a initial role in pulse compression. Fig. 2(a) shows the waveform of the input and output pulse. The $F_c=2.79$, the length of SMF is 6 km, and the net gain of EDFA is 6dB. The output pulse has a large pedestal, in order to compress the pedestal, comb-like fiber is proposed[10-11]. A cascaded structure is used for furthur compression. The peakpower of the output pulse is 2.04 W. Because of the great disparity between the input and output pulses, normalization processing was made for contrast the pulse envelope of the input and output clearly in Fig. 2

Fig. 2(b) shows the input and output pulse waveform using the SMF+HNLF scheme(Scheme 2). The $F_c=9.62$, which means the width of the pulse is notably compressed. Compared to the scheme we proposed, the parameter of this scheme is drastically changed, for the γ of SMF and HNLF is 1.314 $W^{-1}km^{-1}$ and 11.44 $W^{-1}km^{-1}$, respectively. Without the DSF between SMF and HNLF, the output pulse still has a large pdestal (R=44.7%), in spite of the F_c is much larger than the former scheme. The peakpower of the output pulse is 1.67 W.



(a)Scheme (b)Scheme 2 (c)Scheme 3

Fig. 2 The input and output pulse of Scheme 1～3

Fig. 2(c) shows the waveform using step-like nonlinearity profiled fiber we proposed (Scheme 3). The F_c=9.77, nearly same as the waveform shown in Fig. 2, but it has a small pedestal relatively(R=21.4%). Compare to Scheme 2, the changing of parameters is relatively gentle. In fact, the output pulse of Scheme 1 is the input pulse which is transmitting in the HNLF in Scheme 3, so Scheme 3 has a smaller pedestal than Scheme. 2. According to equation (2), in Scheme 3 $N<1$, which means the GVD effect is important than SPM in transmission. The properties which the pulse transmitting in HNLF are shown in Fig. 3. Since the SPM-induced chirp is linear only over the central part of the pulse, the central part is compressed by the anomalous GVD of the HNLF. Furthermore, the GVD is dominant in Scheme 3, and the F_c is increasing as the pulse propagating. But energy in the pulse wings remains uncompressed and appears as a broad pedestal[12].

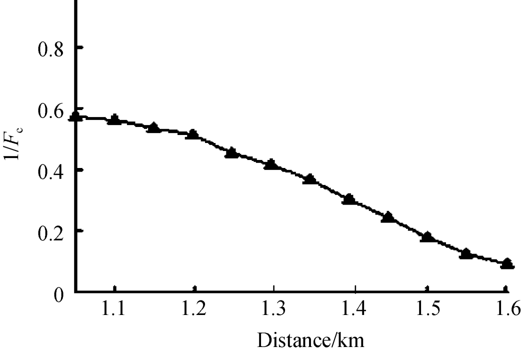


Fig. 3 F_c vs length of HNLF

As shown in Fig. 4, the F_c could be adjusted flexible by changing the gain provided by EDFA. With the introduction of EDFA, F_c could be altered without changing the length of fiber, which increased the applicability of the system.

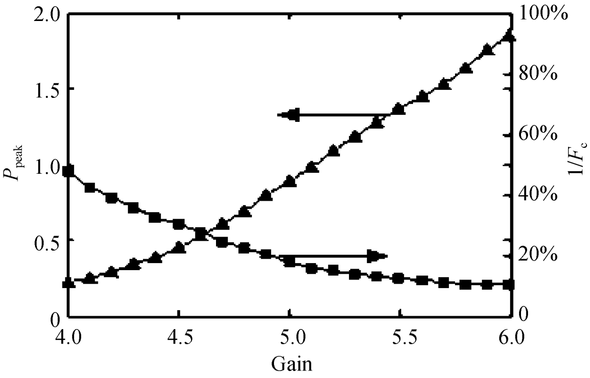


Fig. 4 The P_{peak} and F_c of the pulse vs the net gain provided by EDFA

3 Conclusion

In this paper, a compressor consisting of step-like nonlinearity profiled fiber was proposed. All the components used in the simulation are available in reality and low cost. Using this method a 12.5 ps hyperbolic secant pulse was compressed by 9.77-fold, down to 1.28 ps. With the unique characteristics of HNLF, the structure of the compressor could be step-like, much more easy to operate than the comb-like fiber. Because of the γ is steeply changed, the compression process isn't consistent with the adiabatic condition anymore, so the compressed pulse has a pedestal. The pedestal coule be removed by pedestal-free technique.

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一种基于阶梯状非线性光纤的新颖脉冲压缩方法

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摘　要:提出了一种基于阶梯状非线性光纤的脉冲压缩方法.阶梯状非线性光纤包括普通单模光纤,色散位移光纤和高非线性光纤.数值模拟中所使用的所有元件均在现实中存在,并且与其他脉冲压缩方法相比,此方法成本低且易于控制.数值模拟表明:12.5 ps脉宽,300 mW峰值功率的双曲正割脉冲可被压缩至1.28 ps脉宽,1.3 W峰值功率的脉冲.

关键词:非线性光学;光脉冲压缩;孤子;高非线性光纤

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