Numerical Investigation of a Novel Two-stage Structure to Compress Spectrum and Suppress Pedestal Employing a DIF Interconnected with a HNLF-NOLM

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Abstract— A novel all-fiber spectral compression scheme is proposed and demonstrated, which is based on a two-stage structure employing a dispersion increasing fiber interconnected with a nonlinear optical loop mirror. Five sorts of DIF with different distribution of dispersion coefficient is analyzed one by one in the two-stage scheme. Numerical simulation result shows Logarithmic DIF is suitable for the two-stage scheme, obtain a SCR as high as 10.93 without a Raman self-frequency soliton shift under the condition of soliton number is equal to 1.4.

1. INTRODUCTION

All-optical analog-to-digital conversion (ADC) is the key technique to convert optical analog signals into optical digital ones, in which the whole process is realized in the optical domain. In an all-optical ADC based on Raman self-frequency shift quantization scheme, the resolution, one of the vital factors, can be effectively enhanced by compressing the spectrum after SSFS [1]. The basis of the spectral compression in an optical fiber is the compensation between the initial negative chirp of an optical pulse and the positive chirp introduced by the self phase modulation (SPM) effect. Spectral compression, a common technology in the passive picosecond pulse shaping [2], can be achieved through passing an initially highly negative-chirped optical pulse through an optical fiber [3, 4]. It can also be realized through passing a transform-limited optical pulse (or an optical pulse with a low chirp) through an anomalous dispersion fiber [5, 6].

In this paper, a novel two-stage architecture, employing a DIF as the first stage and an NOLM composed of an HNLF in the loop as the second stage, is introduced. The first DIF achieves the spectral compression, while the nonlinear optical loop mirror (NOLM) consisting of a high-nonlinear fiber (HNLF), HNLF-NOLM for short, is proposed for pedestal elimination due to the chirp-related intensity filtering effect of NOLM. Spectral compression with a large compression ratio is achieved in a two-stage structure composed of DIF concatenating a feed through HNLF-NOLM.

2. OPERATION PRINCIPLE

Figure 1 shows the configuration of the proposed two-stage scheme based on the interconnection between DIF and HNLF-NOLM. HNLF-NOLM is composed of a DIF and an optical coupler with a power-coupling ratio of $\alpha : 1 - \alpha$ ($\alpha \neq 0.5$). The spectral compression principle is analyzed as follow. The SMF is used to pre-chirp the input pulse, the two-stage structure of DIF and HNLF-NOLM is employed to compensate the negative chirp through the SPM effect, providing two-stage spectral compression. The spectral pedestal after compression is eliminated by the chirp-related intensity filtering effect of the NOLM architecture [7], the dispersion-induced chirp is linear and negative, the SPM-induced chirp is nearly linear and positive, which is mainly distributed around the center of pulse ($-0.5T_0 < T < 0.5T_0$). The origin of the spectral pedestal is the insufficient compensation of the nonlinear chirp at the leading and trailing edge of the optical pulse, which correspond to low-power chirp-related edges of the pulse in the time domain. Therefore, it can be efficiently filtered out in NOLM architecture which has a well-known intensity filtering effect [7].

3. SIMULATION

Simulation setup is shown in the Figure 2. A 20 m-long single-mode fiber with a GVD value of 15 ps/nm/km, which induce a linear negative chirp, is connected with the DIF. The output of DIF

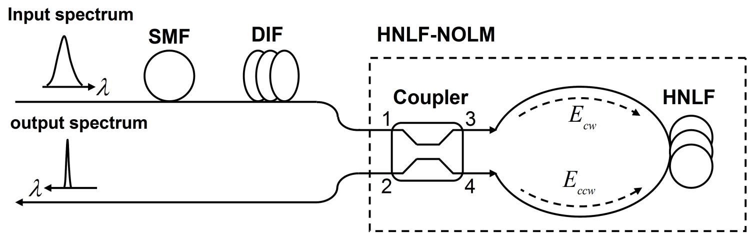


Figure 1: Configuration of the two-stage scheme.

is involved in the port 1 of the HNLF-NOLM. The HNLF-NOLM is composed of a coupler with a coupling ratio of 60/40 and the HNLF whose nonlinear coefficient, loss coefficient and length are $27\,\mathrm{W^{-1}km^{-1}}$, 0.939 dB/km and 1000 m, respectively. A chirp-free hyperbolic-secant pulse, with a central wavelength of 1560 nm, a duration of 300 fs (FWHM) and a peak power of 6.667 W, is used as the input.

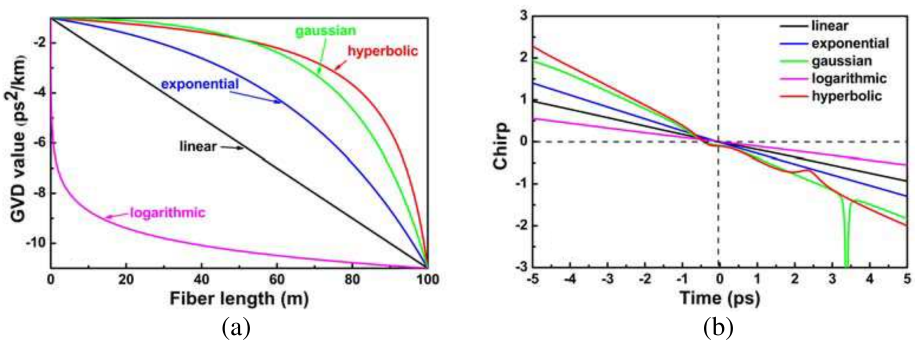


Figure 2: (a) Five sorts of DIF with different distribution of dispersion coefficient. (b) The chirp after pulse propagation in five kinds of DIF.

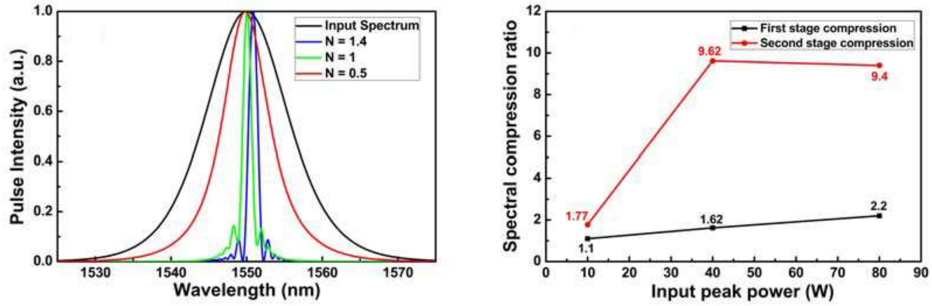
The propagation of a single optical pulse in a SMF or/and DIF is described by the GNLS equation [19]. The evolution of the two counter propagating pulses in the HNLF-NOLM is described by the coupled generalized nonlinear Schrödinger equations [19] (GNLS). Both GNLS and coupled GNLS equations are solved by using the split-step Fourier method for simulating the spectral compression procedure in the two-stage structure. Spectral compression ratio (SCR), defined as the ratio of the input to the output spectral width (FWHM), is used to evaluate the spectral compression performance. There are five sorts of DIF differentiated with the distribution of dispersion coefficient (β_2). Figures 2(a) and (b) illustrate distribution of five different GVD values of DIF and the pulse chirp after the propagation in the DIF (pulse peak power = 80 W), respectively. With varied soliton number by changing the input pulse peak power (10 W, 40 W and 80 W, corresponding to $N = 0.5$, 1, 1.4), spectral compression is numeric simulated under the condition of five different DIF one by one.

3.1. Linear DIF

Figure 3(a) represent spectrum evolution of two-stage spectral compression structure with the input peak powers of 10 W, 40 W and 80 W, which correspond to the soliton number N of 0.5, 1 and 1.4, respectively. The black line is the input spectrum, the red line is the spectrum outputted when $N = 0.5$, the green line is the output spectrum when $N = 1$, and the blue line is the output spectrum when $N = 1.4$, respectively. Figure 3(b) illustrates the SCR with the different input peak powers. The simulated result show that a higher soliton number leads to a better spectral compression ratio. But a 1.4 nm frequency shift to "red band" when $N = 1.4$ according to the Raman soliton self-frequency shift effect caused by the high enough pulse power.

3.2. Hyperbolic DIF

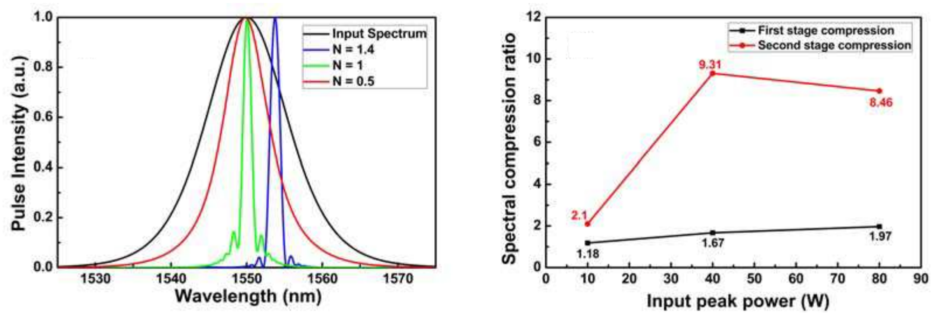
Figure 4(a) represent spectrum evolution of two-stage spectral compression structure with the input peak powers of 10 W, 40 W and 80 W, which correspond to the soliton number N of 0.5, 1 and 1.4, respectively. The black line is the input spectrum, the red line is the spectrum outputted when $N = 0.5$, the green line is the output spectrum when $N = 1$, and the blue line is the output



(a) (b)

Figure 3: (a) Spectrum evolution of two-stage spectral compression structure employed a linear DIF with the input peak powers of 10 W, 40 W and 80 W (red line, $N = 0.5$; green line, $N = 1$; blue line, $N = 1.4$, respectively). (b) SCR with the different input peak powers.

spectrum when $N = 1.4$, respectively. Figure 4(b) illustrates the SCR with the different input peak powers. The result shows that a higher spectral compression ratio is provided when soliton number is equal to 1, increasing SCR from 1.67 of first stage compression to 9.31 of second stage compression. However, it is obvious that more pedestal is raised simultaneously. A 3.25 nm Raman soliton self-frequency shift is also existed when soliton number is 1.4.



(a) (b)

Figure 4: (a) Spectrum evolution of two-stage spectral compression structure employed a hyperbolic DIF with the input peak powers of 10 W, 40 W and 80 W (red line, $N = 0.5$; green line, $N = 1$; blue line, $N = 1.4$, respectively). (b) SCR with the different input peak powers.

3.3. Exponential DIF

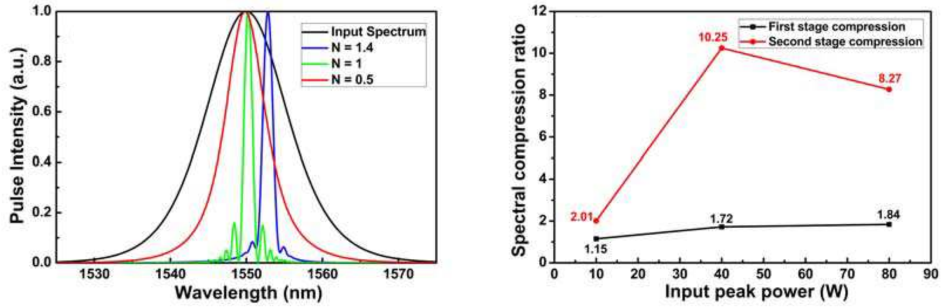
Figure 5(a) represent spectrum evolution of two-stage spectral compression structure with the input peak powers of 10 W, 40 W and 80 W, which correspond to the soliton number N of 0.5, 1 and 1.4, respectively. Figure 5(b) shows the SCR with the different input peak powers. It is implied that a higher SCR of 10.25 is obtained when N is equal to 1, but the side-lobe component level is larger at the same time. A 3.1 nm Raman soliton self-frequency shift is accompanied with spectral compression when N is equal to 1.4.

3.4. Gaussian DIF

Figure 6(a) represent spectrum evolution of two-stage spectral compression structure with the input peak powers of 10 W, 40 W and 80 W, which correspond to the soliton number N of 0.5, 1 and 1.4, respectively. Figure 6(b) displays the SCR with the different input peak powers. Similar conclusion can be arrived as described above. It should be noted that 5 nm Raman self-frequency shift is existed which is the longest shift in simulation.

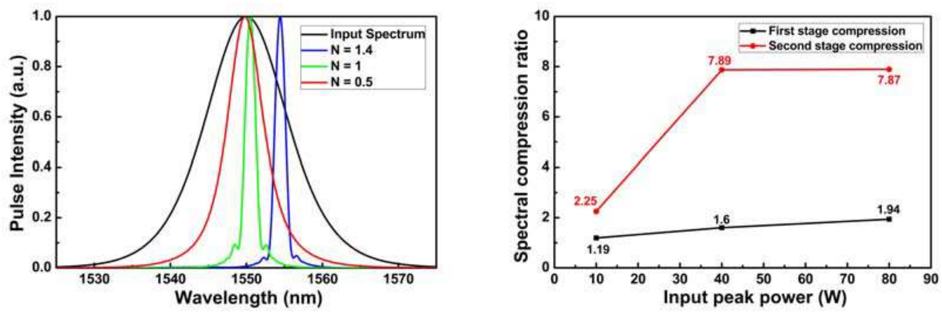
3.5. Logarithmic DIF

Figure 7(a) represent spectrum evolution of two-stage spectral compression structure with the input peak powers of 10 W, 40 W and 80 W, which correspond to the soliton number N of 0.5, 1 and 1.4, respectively. Figure 7(b) displays the SCR with the different input peak powers. Different with other four kinds of DIF, a better SCR is achieved under condition of soliton number is 1.4, along with a bigger pedestal and a higher side-lobe component which may degrade the system



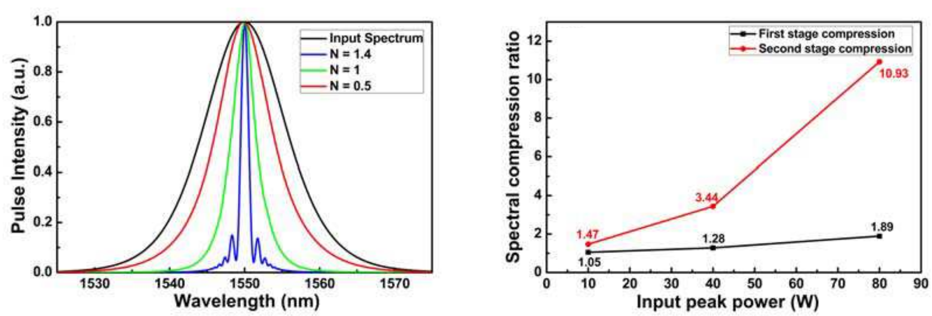
(a) (b)

Figure 5: (a) Spectrum evolution of two-stage spectral compression structure employed a exponential DIF with the input peak powers of 10 W, 40 W and 80 W (red line, $N = 0.5$; green line, $N = 1$; blue line, $N = 1.4$, respectively). (b) SCR with the different input peak powers.



(a) (b)

Figure 6: (a) Spectrum evolution of two-stage spectral compression structure employed a Gaussian DIF with the input peak powers of 10 W, 40 W and 80 W (red line, $N = 0.5$; green line, $N = 1$; blue line, $N = 1.4$, respectively). (b) SCR with the different input peak powers.



(a) (b)

Figure 7: (a) Spectrum evolution of two-stage spectral compression structure employed a logarithmic DIF with the input peak powers of 10 W, 40 W and 80 W (red line, $N = 0.5$; green line, $N = 1$; blue line, $N = 1.4$, respectively). (b) SCR with the different input peak powers.

performance. Moreover, there is no Raman soliton self-frequency shift which is the key for the spectral compression and the resolution improvement of all-optical quantization.

4. CONCLUSION

In a conclusion, a novel two-stage spectral compression structure is presented, employed a DIF as the first stage and an NOLM composed of an HNLF in the loop as the second stage. Five sorts of DIF with different distribution of dispersion coefficient is analyzed one by one in the two-stage scheme. Spectral compression ratio, which is defined as the ratio of the input to the output spectral width (FWHM), is used to describe the performance scheme. Numerical simulation result shows Logarithmic DIF is suitable for the two-stage scheme, obtain a SCR as high as 10.93 without a Raman self-frequency soliton shift under the condition of soliton number is equal to 1.4.

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