12th Optoelectronics and Communications Conference/16th International Conference on Integrated Optics and Optical Fiber Communication (OECC/IOOC2007)
Technical Digest, July 2007, Pacifico Yokohama

13C1-4

Bragg Soliton Pulse Compression in Non-Uniform Fiber Bragg Gratings

K. Senthilnathan[1], Qian Li[1], P. K. A. Wai[1] and K. Nakkeeran[2]

[1] Photonics Research Center, Department of Electronic and Information Engineering, The Hong Kong Polytechnic University, Hung Hom, Hong Kong. Tel: +852-2766-6231, Fax: +852-2362-8439, Email: enwai@polyu.edu.hk

[2] *Department of Engineering, Fraser Noble Building, King's college, University of Aberdeen, Aberdeen AB24 3UE, UK.*

Abstract: We demonstrate the Bragg soliton pulse compression in an exponentially dispersion decreasing fiber Bragg grating. Exponential profile is also approximated as six discrete uniform sections. Nearly transform-limited pulse is achieved in both cases.

1. Introduction

Generation of short pulses has always been of great scientific and technological interests. Optical pulse compression is an important technique to generate ultrashort optical pulses which find many applications especially in ultra high bit-rate communication systems [1]. Soliton-effect and adiabatic pulse compression techniques have been used for pulse compressors. In soliton pulse compression technique, the compressed pulses typically suffer from significant pedestal generation. Adiabatic pulse compression technique has been used to generate a stable train of pedestal-free pulses but it requires long length of fiber. Optical periodic structures or photonic band gap (PBG) materials such as fiber Bragg gratings (FBGs) have large dispersion (six orders of magnitude larger) compared to silica fibers [1]. Hence, the soliton dynamics could be studied on length scales of centimeters. Moores suggested that chirped solitary waves can be compressed more efficiently if the dispersion decreases approximately exponentially [2]. Recently, self-similar analysis has been utilized to study linearly chirped pulses in fiber amplifiers [3]. In this work, we investigate the possibility of pedestal-free Bragg soliton pulse compression.

2. Pulse Propagation in FBG

Two theoretical models have been used to describe nonlinear pulse propagation in FBGs. The first model uses the nonlinear coupled mode (NLCM) equations which describe the coupling between forward and backward traveling modes [1]. The second model is based on the nonlinear Schrödinger (NLS) type equation which is reduced from the NLCM equations using the multiple scale analysis [1, 4, 5]

$$i\frac{\partial E}{\partial z}-\frac{\beta_2^g(z)}{2}\frac{\partial^2 E}{\partial t^2}+\Gamma^g\,|E|^2E=0, \qquad (1)$$

where $E(z,t)$ is the envelope of the Bloch wave associated with the grating, z is the distance variable , t is the time variable, β_2^g represents the dispersion of the grating, and Γ^g is the effective nonlinear coefficient. For Eq. (1), adiabatic Bragg soliton pulse compression has been discussed wherein the maximum compression factor 4 was achieved [4,5] and the pedestals generated is very small [4]. In what follows, using self-similar analysis, we show that one can achieve pedestal-free compression with maximum compression factor beyond the limit obtained by the adiabatic compression process. The self-similar solution to Eq. (1) is given by

$$E(z,t)=\frac{1}{\sqrt{1-\alpha_{20}D(z)}}R\left(\frac{t-t_c}{1-\alpha_{20}D(z)}\right)\exp[i\alpha_1(z)+i\alpha_2(z)(t-t_c)^2]$$

,where $\alpha_1(z)=\alpha_{10}-\frac{\lambda_1}{2}\int_0^z\frac{\beta_2^g(z')\,dz'}{(1-\alpha_{20}D(z'))^2}$,

$\alpha_2(z)=\frac{\alpha_{20}}{1-\alpha_{20}D(z)}$, $D(z)=2\int_0^z\beta_2^g(z')\,dz'$,and α_{10}, λ_1, and α_{20} are the integration constants. The self-similar solution is possible if and only if the dispersion varies exponentially, i.e.

$$\beta_2^g(z)=\beta_{20}^g\exp[-2\alpha_{20}\beta_{20}^g z]. \qquad (2)$$

The function $R(\theta)$ obeys the equation $\frac{d^2R}{d\theta^2}-\lambda_1 R+2\lambda_2R^3=0$, where the scaling variable θ and the coefficient λ_2 are given by $\theta=\frac{t-t_c}{1-\alpha_{20}D(z)}$, and $\lambda_2=-\frac{\Gamma^g}{\beta_2^g(0)}$ respectively. Finally, the bright solitary wave is given by

$$E(z,t)=\sqrt{\frac{\beta_2^g(z)}{\Gamma^g}}\frac{1}{t_0(1-\alpha_{20}D(z))}\operatorname{sech}\left(\frac{t-t_c}{t_0(1-\alpha_{20}D(z))}\right),$$
$$\exp[i\alpha_1(z)+i\alpha_2(z)(t-t_c)^2], \qquad (3)$$

where the integration constant λ_1 is equal to $1/t_0^2$, and t_0 is the initial pulsewidth. Equations (2) and (3) are the key results of this work which state that efficient pedestal-free Bragg soliton pulse compression is possible using a nonlinear FBG with an exponentially decreasing dispersion profile. The pulse compression factor is given by $t_0/t(z)=\exp(2\alpha_{20}\beta_{20}^g z)$ which also equals to the ratio of the initial and final dispersion values.

3. Bragg Soliton Pulse Compression

Self-similar analysis reveals that the dispersion has to be decreased exponentially in the grating. However, such careful profiling of FBG dispersion is not easy in practice. Therefore, we considered FBGs with stepwise approximation (SWA) of the exponentially decreasing dispersion FBG (DDFBG). Stepwise decreasing dispersion could easily be realized by concatenated FBG sections with discrete uniform dispersions. Therefore, Bragg soliton compression studies have been carried out for both DDFBG and SWA. We assume a grating length L = 6 cm and the initial pulse width t_0 = 10 ps. The initial grating induced dispersion is β_2^g = −33 ps^2/cm and it decreases to $\beta_2^g(L)$ = −4.56 ps^2/cm for a given initial chirp α_{20} = −0.005 THz^2. The compression factor is ~7 in both cases. The exponentially DDFBG can be approximated as six discrete uniform sections. If M section is used to approximate exponentially DDFBG, the constant dispersion value b_i at the i-th section is given by

$$b_i = \int_{(i-1)\frac{L}{M}}^{i\frac{L}{M}} \beta_{20}^g \exp\left(-2\alpha_{20}\beta_{20}^g z'\right)dz' / \left(\frac{L}{M}\right) \qquad (4)$$

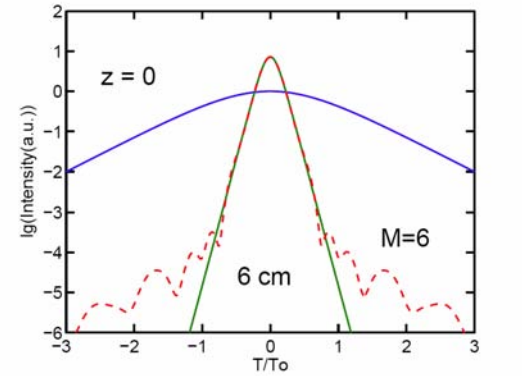

Fig. 1. Bragg soliton pulse compression for exponential DDFBG (solid lines) and stepwise approximation (dashed lines) with 6 sections.

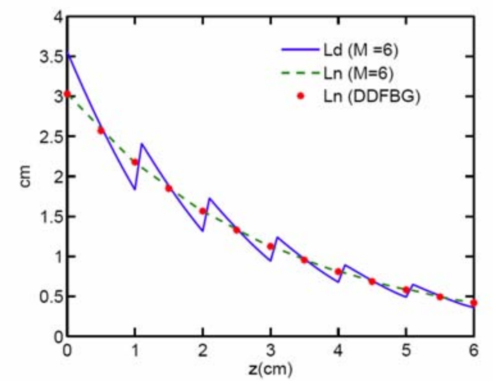

Fig. 2. Evolution of dispersion and nonlinear lengths. Solid and dashed lines-SWA. Dots-exponential profile.

Figure (1) shows the Bragg soliton pulse compression for the exponentially DDFBG as well as SWA dispersion profiles. Note that no pedestal generation is observed in the exponential profile whereas small pedestals do appear (1.12%) in the SWA profile. The evolutions of the dispersion and nonlinear lengths are given in Fig.(2) during the self-similar Bragg soliton pulse compression for both profiles. Figure (3) gives the broadening of the bandwidth during the Bragg soliton pulse compression for both profiles considered in this work.

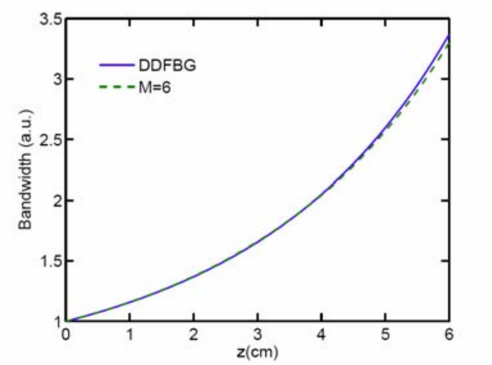

Fig. 3. Bandwidth for exponential DDFBG (solid line) and stepwise approximation (dashed lines).

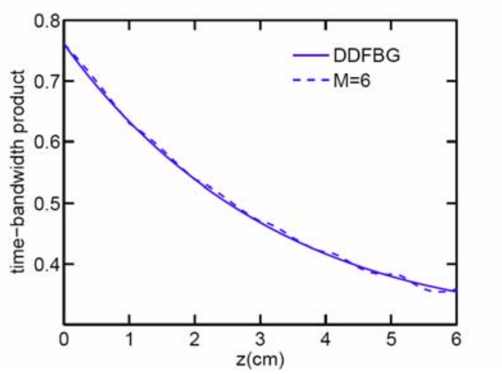

Fig. 4. Time-bandwidth product for exponential DDFBG (solid line) and stepwise approximation (dashed lines).

Figure (4) represents the time-bandwidth product of the pulse during the compression process in exponential DDFBG and SWA profiles. Eventually, the compressed pulse goes to the transform limited case since the (normalized) chirp decreases during the compression process.

4. Conclusions

Bragg soliton pulse compression has been investigated for both exponentially dispersion decreasing FBG as well as stepwise approximation to exponentially dispersion decreasing FBG. No pedestals are observed in the exponential profile. Only a small amount of pedestals (1.12%) appeared when the exponentially decreasing FBG is approximated by concatenated FBG sections with discrete uniform dispersions. Nearly transform-limited pulse has been achieved in the both cases.

5. References

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