

# An novel approach to improve switch performance of linear negative tapered Bragg gratings

JIAN-FENG TIAN

Department of Physics, Taiyuan Normal University, Taiyuan 030031, China

Based on the coupled mode theory, the influence of the introducing chirp on the bistable characteristics of linear negative tapered Bragg gratings have been investigated. The results show that introducing positive chirp is helpful to improve the bistable performance of linear negative tapered Bragg gratings; and the bistable performance can be further optimized by reasonably selecting the length of the linear negative-tapered Bragg gratings with positive chirp.

(Received August 31, 2009; accepted September 30, 2009)

*Keywords:* Bragg gratings, Linear chirp, Linear negative tapered, Bistability

## 1. Introduction

Nonlinear Bragg gratings (NLBG) act as an important optical device in fiber communication field due to particular properties [1-3]. Outside “photonic band gap”(PBG), slow Bragg soliton related to great anomalous group velocity dispersion(GVD) has been used for ultra-short optical pulse compression successfully [4-6]; Inside PBG, a positive feedback loop(among inner optical intensity, nonlinear refractive index, and Bragg resonance) causes optical bistability phenomena. In recent years, many efforts have been made to improve bistable performance of NLBG, such as the switching-on threshold, the switching time, the on-off switching ratio and dynamic stability, etc. The used technologies mainly include spatial taper, phase shift, chirp and nonlinear refractive index axial varying, etc. In paper [15], it investigated the bistable performance of linearly negative tapered NLBG. Based on this, in this article ,a novel scheme has offer to further improve linear negative tapered NLBG. The results show that introducing positive chirp can improve bistable performance of linear negative tapered NLBG and the bistable performance can be further optimized by reasonably selecting the length of grating.

## 2. Theoretical model

Inside fiber gratings, the z-axial distribution of refractive index can be described by:

$$n(z) = n_0 + n_1(z) \cos\left[\frac{2\pi}{\Lambda} z + \phi(z)\right] + n_2 |E(z)|^2 \quad (1)$$

where  $E(z)$  is the inner electric field of grating,  $\Lambda$  is the grating period,  $\phi(z)$  is the spatial phase shift.  $n_0$ ,  $n_1(z)$  and  $n_2$  denote the effective mode refractive index, linear refractive index modulation amplitude, and

nonlinear refractive index coefficient, respectively.

The inner electric field can be expressed by:

$$E = A_f \exp[i(\beta_0 z - \omega t)] + A_b \exp[-i(\beta_0 z + \omega t)] \quad (2)$$

where  $\omega$  is the carrier angular frequency,  $t$  is the time,  $\beta_0 = \pi / \Lambda$  is the Bragg wave number,  $A_f$  and  $A_b$  represent the slowly varying amplitude of forward and backward wave, respectively. In this paper, assuming that the incident wave is continuous wave.

Substituting Eqs. (1) and (2) into the wave equations, and neglecting the loss and material dispersion (the nonlinear medium of NLBG is assumed to be Erbium-doped fiber without pump, even though its loss and material dispersion coefficients near 1.55  $\mu\text{m}$  are large, the total loss and material dispersion are negligible due to very short length selected in calculations), the response time of material is very fast enough, as well as the carrier wavelength is close to Bragg wavelength, one can obtain the following nonlinear couple-mode equations[5]:

$$\frac{\partial A_f}{\partial z} + \frac{1}{v_g} \frac{\partial A_f}{\partial t} = i[\delta A_f + \Gamma(|A_f|^2 + 2|A_b|^2)A_f + k A_b] \quad (3a)$$

$$\frac{\partial A_b}{\partial z} - \frac{1}{v_g} \frac{\partial A_b}{\partial t} = -i[\delta A_b + \Gamma(|A_b|^2 + 2|A_f|^2)A_b + k^* A_f] \quad (3b)$$

where  $v_g$  is the light group velocity in the grating medium,  $\delta$ ,  $\Gamma$  and  $k$  account for the detuning, nonlinear coefficient, and coupling coefficient, respectively, which can be expressed by

$$\delta = \beta - \beta_0 = n_0 \frac{\omega}{c} - \beta_0, \quad \Gamma = \frac{2\pi n_2}{\lambda_0}, \quad k(z) = \frac{\pi n_1(z)\eta}{\lambda_0} \exp[i\phi(z)] \quad (4)$$

where  $c$  is the light velocity in vacuum,  $\lambda_0 = 2n_0\Lambda$  is the Bragg wavelength,  $\eta$  is the confinement factor.

For linear negative tapered NLBG,  $k$  can be written as [13]:

$$k(z) = k_0[1 + \Delta k(z - L/2)/L] \quad (5)$$

where  $L$  is the total length of grating,  $k_0$  is the coupling coefficient of the grating center, and  $\Delta k$  characterizes the variation slope of coupling coefficient. A positive (negative) value of corresponds to the positive (negative) tapered.

For a linear chirped NLBG, the Bragg wave number  $\beta_0$  becomes  $z$ -dependent and can be written as [13]:

$$\beta_0(z) = \overline{\beta_0} + \frac{C}{L^2}(z - \frac{L}{2}) \quad (6)$$

where  $\overline{\beta_0}$  is the average Bragg wave number, a positive (negative) value of  $C$  corresponds to the positive (negative) chirped, and the magnitude of  $C$  represent the total change in  $\beta_0(z)L$  along the device. For small amounts of spatial chirp, the coupled-mode equations remain unchanged except that the detuning parameter  $\delta$  now becomes  $z$ -dependent.

The boundary conditions are given by:

$$z=0 : A_f(0,t) = A_i(0,t) \quad A_r(0,t) = A_b(0,t) \quad (7a)$$

$$z=L : A_b(L,t) = 0, \quad A_t(L,t) = A_f(L,t) \quad (7b)$$

where  $A_i$ ,  $A_r$  and  $A_t$  are the slowly varying amplitudes of the incident, reflected and transmitted wave, respectively.

Setting the spatial derivative with respect to  $t$  in Eqs. (3a) and (3b) equal to zeros, the axial evolving equations of slowly varying amplitude under steady-state can be analyzed numerically by means of the fourth-order Runge-Kutta method together with boundary conditions.

### 3. Results and discussion

The used data in calculations are [15]  $\lambda_0 = 1.55\mu m$ ,  $n_0 = 1.46$ ,  $n_2 = 6.9 \times 10^{-15} m^2/w$ ,  $\eta = 0.8$ . To facilitate description, the input and output light intensity  $I_i$ ,  $I_t$  are normalized as  $I_i/I_c$ ,  $I_t/I_c$  respectively in following discussions. Where  $I_c = 4\lambda_0/(3\pi n_2 L)$  is the critical input intensity [13].

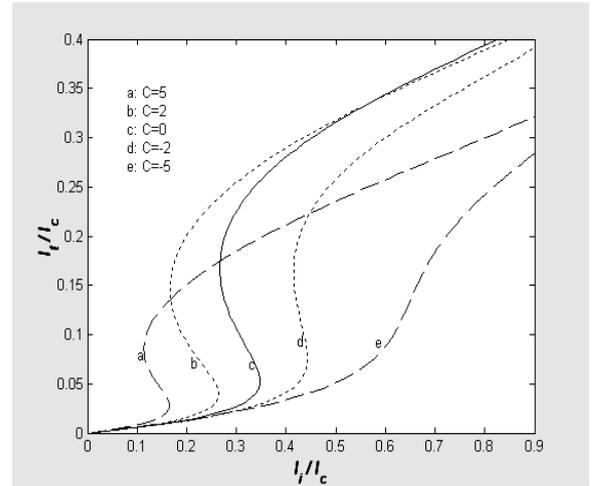


Fig. 1. Input-output characteristics of linear negative tapered NLBG for various linear chirp  $C$ .

Fig. 1. shows the steady-state input-output characteristics of linear negative tapered NLBG for various linear chirp  $C$ . Where  $\Delta k = -1$ ,  $\delta L = 2.5$  (which is near an edge of PBG)  $k_0 = 3 cm^{-1}$ ,  $L = 1cm$ . From Fig.1, it can be seen that, introducing negative chirp increases the switching-on threshold, the width of the hysteresis decrease rapidly, even the bistable phenomena vanish with increase of the amount of the negative chirp; while introducing positive chirp, with the increase of the positive chirp, the upper branch becomes flatter, the on-off switching ratio decreases, but the switching threshold decreases significantly. As a result, introducing positive chirp is helpful to improve the bistability performance of linear negative tapered NLBG.

Figs. 2 and 3 show that, for various detuning, the steady-state input-output characteristics of nonchirped ( $C=0$ ) and linearly positive chirped ( $C=5$ ) linear negative tapered NLBG, respectively. As in Fig. 2, for the nonchirped linear negative tapered NLBG, the highest value of the detuning  $\delta L = 3$  is chosen near the onset of bistability and  $\delta L$  decreased to 1.8 when the switch-on input intensity reaches to 0.6 of the critical intensity (given by the curve  $g$ ); for the linearly positive chirped case, as in Fig. 3, the highest value of the detuning  $\delta L = 3$  is the same as the nonchirped case, however,  $\delta L$  decreased to 0.8 when the switch-on input intensity also reaches to 0.6 of the critical intensity (given by the curve  $l$ ). As a result, the addition of positive linear spatial chirp to the linear negative tapered NLBG increases significantly the incident wavelength range that observe optical bistability.

In addition, by comparing the bistability characteristics of linear negative tapered NLBG with and without spatial chirp for a fixed frequency incident light, i.e. for a fixed value of  $\delta L$ , introducing positive spatial chirp decreases the on-off switching ratio of the bistable switching, whereas it decreases significantly the switching threshold, and the upper branch of the hysteresis become flatter. These features may be understood as follows: the addition of chirp makes Bragg wavenumber becomes z-dependent, and more incident lights experience resonance amplification due to satisfying the Bragg conditions, therefore widen the bistable wavelength range; however, axial varies of Bragg wavelength reduce the times of resonance amplification for the incident light at a given frequency, so the inner feedback of grating become weaker and the transmittance of the upper branch reduces, therefore, the on-off switching ratio become small.

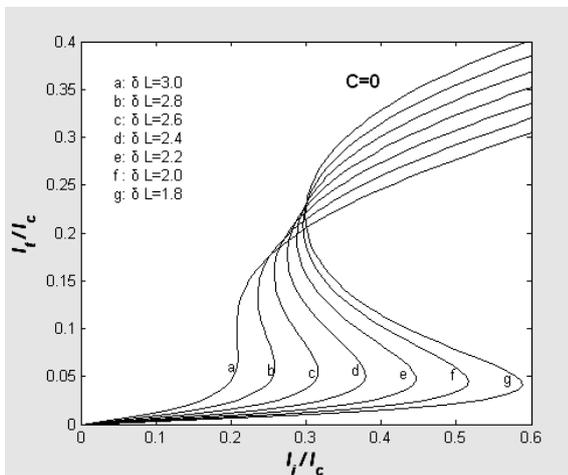


Fig. 2. Input-output characteristics of nonchirped( $C=0$ ) linear negative tapered NLBG for various detuning.

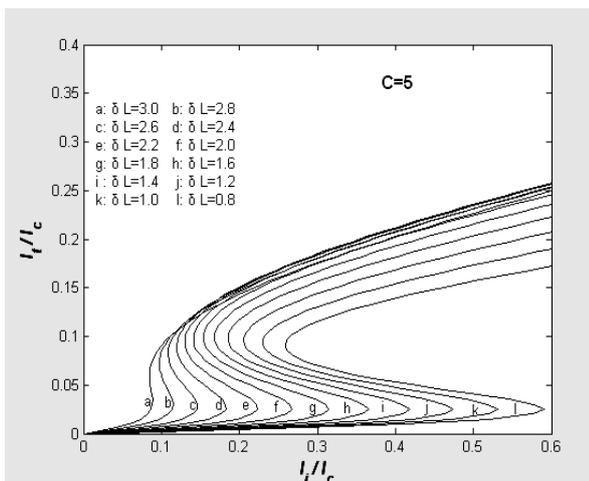


Fig. 3. Input-output characteristics of positive chirped( $C=5$ ) linear negative tapered NLBG for various detuning.

As a result, introducing positive chirp in linear negative tapered NLBG will be helpful to decrease the

switching threshold, flatten the upper branch of hysteresis, and widen the bistable wavelength range.

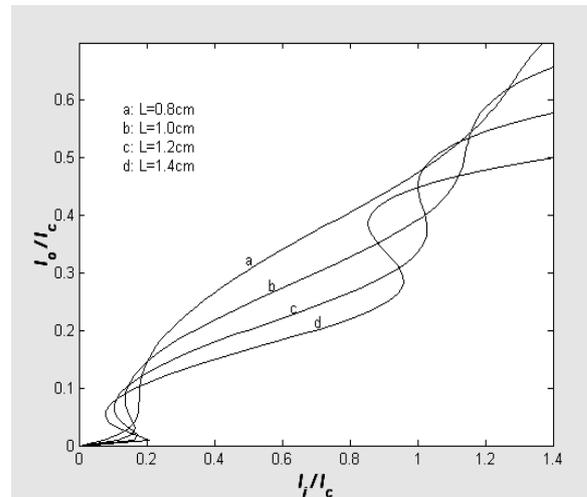


Fig. 4. Input-output characteristics of the linear positive-chirped negative-tapered grating for the various length.

Fig. 4 shows the steady-state input-output characteristics of the linear positive-chirped negative-tapered NLBG for the different grating length. Where  $\Delta k = -1$ ,  $\delta = 2.5 \text{ cm}^{-1}$ ,  $k_0 = 3 \text{ cm}^{-1}$ . From the figure, it can be seen that, the grating length have obvious influence on the bistable characteristics, such as the switching-on threshold, the on-off ratio and the width of the hysteresis. When length is smaller ( $< 0.8 \text{ cm}$ ), no bistable phenomena occurs. With the gradual increasement of length, the bistable effect begin to occurs, moreover the hysteresis width become bigger, for the bigger length, it exists two hysteresis. As a result, the bistable performance can be further optimized by reasonably selecting the grating length of the the linear positive-chirped negative-tapered grating.

#### 4. Conclusions

By using the nonlinearly coupled mode theory, this paper has demonstrated the influence of introducing chirp on the bistable characteristics of linear negative tapered Bragg gratings. The numerical simulations show that, introducing positive chirp will be helpful to decrease the switching threshold, flatten the upper branch of the hysteresis, and enlarge significantly the incident wavelength range that observe optical bistability; on the other hand, introducing negative chirp will worsen the bistable performance remarkably. Moreover, the bistable switching performance can be further optimized by reasonably selecting the length of the linear negative tapered Bragg gratings with positive chirp, The results may provide an instructive insight from a practical viewpoint.

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\*Corresponding author: Jianfeng2000@yahoo.com.cn