Dependence of Grating Length of Fiber Gragg Gratings on Slow Light

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Abstract— The influence of grating length of uniform fiber Bragg grating on delay is discussed by using numerical simulation method based on the coupled mode theory and slow light delay characteristics is studied by parameters optimization. The calculated result shows that grating length has a remarkable impact on the delay, when $L < 42.5008$ cm, the $\text{delay}_{\max}$ increases with L increasing, when L tends to 42.5008 cm have a maximum $\text{delay}_{\max}$, the value increased to 3.797 ps, but when $L > 42.5008$ cm, $\text{delay}_{\max}$ decreases with L increasing. This provides basis references for designing slow light components based on fiber Bragg gratings.

1. INTRODUCTION

Fiber Bragg grating has developed dramatically and performed an important role in fiber communications and optical fiber sensing in recent 30 years [1, 2]. Recently, the introduction of slow light with a wide range of novel properties results in unique spectral characteristics of fiber Bragg gratings [3], especially slow light delay of fiber Bragg grating is studied emphatically. K. B. Rochford and S. D. Dyer [4] reported reconstruction of minimum-phase group delay from fiber Bragg grating transmittance or reflectance measurements. The results indicate that phase reconstruction is compared to exact solutions using the reflectance from a uniform grating. An intermediate windowing process improves the recovery accuracy. J. T. Mok, ect. [5] observed 0.68 ns pulses delayed by 4.7 pulse widths in a 30 cm silica FBG without pulse broadening. Improved slow-light delay performance of a broadband SBS system using fiber Bragg grating was reported [6]. Tunable delay slow-light in an active fiber Bragg grating was also studied [7]. These studies provide a very simple approach to control the light group delay. However, this approach requires very high power signal, which limits its practical implications.

In this work, The influence of grating length of uniform fiber Bragg grating on delay is discussed by using numerical simulation method based on the coupled mode theory and slow light delay characteristics is studied by parameters optimization. The calculated result shows that grating length has a remarkable impact on the delay, when $L < 42.5008$ cm, the $\text{delay}_{\max}$ increases with L increasing, when L tends to 42.5008 cm have a maximum $\text{delay}_{\max}$, the value increased to 3.797 ps, but when $L > 42.5008$ cm, $\text{delay}_{\max}$ decreases with L increasing. This provides basis references for designing slow light components based on fiber Bragg gratings.

2. THEORY

Fiber Bragg gratings are produced by exposing an optical fiber to a spatially varying pattern of ultraviolet intensity. For sake of simplicity, we studied an unchirped uniform fiber Bragg grating whose refractive index can be described as follows [8]

$$\delta n_{\mathit{eff}}(z) = \overline{\delta n}_{\mathit{eff}} \left[1 + v \cos\left(\frac{2\pi}{\Lambda} z \right) \right] \tag{1}$$

where $\overline{\delta n}_{\mathit{eff}}$ is the "dc" index change spatially averaged over a grating period, v is the fringe visibility of the index change, Λ is the grating period and

$$\Lambda = \frac{L}{N} \tag{2}$$

where L is the grating length, N is the total number of the grating periods.

According to coupled mode theory, synchronous approximation and the boundary condition of the fiber Bragg grating [9–11]. The amplitude reflection coefficient can be expressed as

$$\rho = \frac{-\kappa \sinh\left(\sqrt{\kappa^2 - \hat{\sigma}^2} L\right)}{\hat{\sigma} \sinh\left(\sqrt{\kappa^2 - \sigma^2} L\right) + i\sqrt{\kappa^2 - \hat{\sigma}^2} \cosh\left(\sqrt{\kappa^2 - \hat{\sigma}^2} L\right)} \tag{3}$$

and the reflectivity

$$\gamma = \left|\rho^2\right| = \frac{\sinh^2\left(\sqrt{\kappa^2 - \hat{\sigma}^2}L\right)}{\cosh^2\left(\sqrt{\kappa^2 - \hat{\sigma}^2}L\right) - \hat{\sigma}^2/\kappa^2} \tag{4}$$

where $\kappa = \pi v \overline{\delta n}_{eff}/\lambda$ is the "ac" coupling coefficient, $\sigma = 2\pi\overline{\delta n}_{eff}/\lambda$ is the "dc" coupling coefficient, $\hat{\sigma}$ is a general "dc" self-coupling coefficient and $\hat{\sigma} = \delta + \sigma$. The detuning δ is defined as

$$\delta = \beta - \frac{\pi}{\Lambda} = 2\pi n_{eff}\left(\frac{1}{\lambda} - \frac{1}{\lambda_B}\right) \tag{5}$$

the Bragg wavelength λ_B is expressed as

$$\lambda_B \equiv 2n_{eff}\Lambda. \tag{6}$$

The delay of the reflected light induced by the fiber Bragg grating can be determined from Eq. (3). If we denote $\theta_\rho = phase(\rho)$, then at a local frequency ω_0 we may expand θ_ρ in a Taylor series about ω_0. Since the first derivative $d\theta_\rho/d\omega$ is directly proportional to the frequency ω, this quantity can be identified as a time delay. Thus, the delay time τ_ρ for reflected light of a grating is expressed as [12]

$$\tau_\rho = \frac{d\theta}{d\omega} = -\frac{\lambda^2}{2\pi c}\frac{d\theta_\rho}{d\lambda} \tag{7}$$

3. CALCULATED RESULTS AND ANALYSIS

3.1. Influence of Grating Length on Delay

Setting $n_0 = 1.46$, $\Delta = 0.002$, $a = 5\,\mu\text{m}$, $N = 20000$, $L = 42.5008\,\text{cm}$, $\overline{\delta n}_{eff} = 0.0001$ and $v = 1$ in Eq. (3), a delay-wavelength curve of a mode can be obtained, in order to studied the slow light delay of the uniform fiber Bragg grating, though not shown here. Let us first discuss the effects of grating length on the delay. When the grating length L is changed, the others were determined, the delay as functions of the wavelength λ can be obtained, so, the maximum value of delays are obtained from the various delays as functions of the wavelength λ. The influence of L on $\text{delay}_{\text{max}}$ is shown in Fig. 1. It can be seen that the $\text{delay}_{\text{max}}$ increases with L increasing, when L tends to 42.5008 cm have a maximum $\text{delay}_{\text{max}}$, the value of $\text{delay}_{\text{max}}$ increased to 3.797 ps, but when $L > 42.5008\,\text{cm}$, $\text{delay}_{\text{max}}$ decreases with L increasing.

In order to further study influence of grating length on delay characteristics in uniform fiber Bragg grating, we calculated the $\text{delay}_{\text{max}}$ as a function of wavelength with $L = 42.5008\,\text{cm}$, shown in Fig. 2. It can be seen that the $\text{delay}_{\text{max}}$ curve becomes rectangle wave and the maximum value of delay is preceded right, which is 3.797 ps. Moreover, the bandwidth is 0.1 nm because of weak grating is to decide from the length.

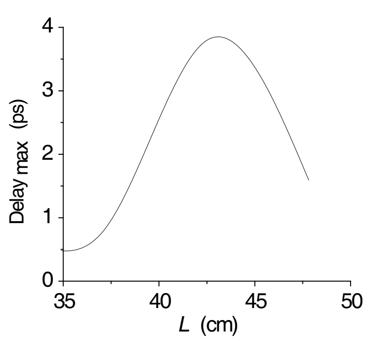

Figure 1: Influence of L on $\text{delay}_{\text{max}}$.

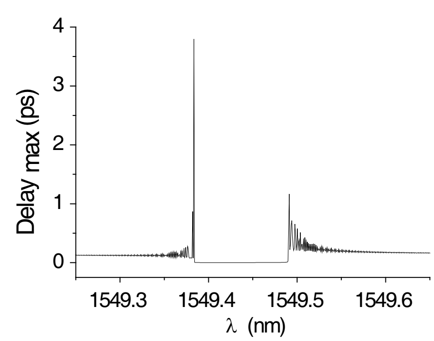

Figure 2: $\text{Delay}_{\text{max}}$ as a function of wavelength with $L = 42.5008\,\text{cm}$.

4. CONCLUSIONS

The influence of grating length of uniform fiber Bragg grating on delay is discussed by using numerical simulation method based on the coupled mode theory and slow light delay characteristics is studied by parameters optimization. The calculated result shows that grating length has a remarkable impact on the delay, when $L < 42.5008\,\text{cm}$, the $\text{delay}_{\max}$ increases with L increasing, when L tends to 42.5008 cm have a maximum $\text{delay}_{\max}$, the value increased to 3.797 ps, but when $L > 42.5008\,\text{cm}$, $\text{delay}_{\max}$ decreases with L increasing. This provides basis references for designing slow light components based on fiber Bragg gratings.

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