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Analysis of dispersion characteristics of long period fiber grating

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Abstract. Present work deals with theoretical analysis of dispersion characteristics of long period fiber grating using straight forward coupled mode theory. Simple analytical solutions are obtained for co propagating core and cladding modes under linear regime. These solutions are used to derive expressions for transmission coefficient (t_{LPG}), phase (ϕ_L), delay (τ_ρ) and group velocity dispersion (D_ρ) for proposed grating structure. Attention is paid to study the delay response of the grating, by varrying physical parameters like incident wavelength and coupling strength of grating. Negative values of group delay for certain value of coupling strength shows that long period fiber can be used as dispersion compansator device in optical fiber communication link.

1. Introduction

Dispersion is an important optical characteristic in the optical fiber, which cause serious limit on the transmission capacity and bandwidth of optical fiber. The major concern of optical fiber communication link has been shifted from compensation of loss to compensation of dispersion. Several techniques have been proposed for dispersion compensation in optical fiber communication [1-4].Nowadays fiber Bragg gratings (FBG) are used for chromatic dispersion compensation by recompressing the dispersed optical signal [5-9].

long period fiber gratings (LPFGs) are of considerable research interest for various light wave communication and sensors application such as gain flattening filters for erbium doped fiber amplifiers, dispersion compensator, add/drop multiplexer, optical fiber polarizer, and strain & temperature sensors [10-14]; because of their simple structure, low insertion loss and negligible delay ripple. The device is very suitable for optical communication link since it works on transmission mode and avoids the use of circulator and chirping the grating. The most significant properties of the LPFG is its tunability for the desired transmission characteristics , by changing the grating parameters like refractive index, modulation depth, grating length and period etc. Dispersion characteristics of LPFG devices play a significant role for high-bit-rate optical communication applications and using as an inline optical device for dispersion compensation. M. das and K. Thyagarajan have proposed the use of uniform LPG fabricated on relatively high refractive index difference fibers as efficient dispersion compensators [11].

In the present work, we have presented a simple theoretical model to analyze delay and dispersion characteristics of long period grating. The analytical expression for amplitude and phase of complex transmission coefficient, delay and dispersion parameter of the grating has been obtained under the linear regime with the help of coupled mode theory. Finally, specific attention is paid to study delay experienced by different frequency components and dispersion compensation capabilities of LPFGs.

2.Theorotical Analysis

Long-period gratings can be considered as a special class of fibre Bragg grating in which the period of the index modulation is such that it satisfies a phase matching condition between the fundamental core mode and a forward propagating cladding mode of an optical fibre. To study the spectral characteristics of grating in linear regime for a continuous wave, following coupled mode equations have been used [15, 16]

$$\frac{\partial A_{core}}{\partial z} = i\delta A_{core} + i\kappa A_{cladd} \qquad (1) \qquad \frac{\partial A_{cladd}}{\partial z} = -i\delta A_{cladd} + i\kappa A_{core} \qquad (2)$$

Here δ and Κ are the detuning parameter and coupling coefficient of grating respectively, define as

$$\delta = \frac{1}{2}\left(\beta_{core} - \beta_{clad} - \frac{2\pi}{\wedge}\right) \qquad (3) \qquad \kappa = \frac{\pi n_g}{\lambda_c} \qquad (4)$$

A general solution of the these linear equation takes the form

$$A_{core}(z) = C_1 e^{iqz} + C_2 e^{-iqz} \qquad (5) \qquad A_{clad}(z) = D_1 e^{iqz} + D_2 e^{-iqz} \qquad (6)$$

Where q is the dispersion parameter of the grating and defined as

$$q = \left(\delta^2 + \kappa^2\right)^{\frac{1}{2}} \qquad (7)$$

In terms of an effective transmission coefficient *t* (*q*) equations (8) and (9) can be written as

$$A_{core}(z) = D_1 e^{iqz}\, t(q) + C_2 e^{-iqz} \qquad (8) \qquad A_{clad}(z) = D_1 e^{iqz} - C_2 e^{-iqz}\, t(q) \qquad (9)$$

$$\text{Where} \quad t(q) = \left(\frac{\kappa}{q+\delta}\right) = \left(\frac{q-\delta}{\kappa}\right) \qquad (10)$$

The 'q' dependency of *t* (*q*) and the dispersion relation (Eq. 10) indicates that both the magnitude and phase of the transmitted wave depends upon the frequency 'ω' of propagating beam in the LPFG.
Using above Equations and on applying the boundary conditions

$$A_{core}(z=0) = 1, A_{core}(z=L) = 1 \qquad (11)$$

The complex transmission amplitude and phase response of LPFG are calculated as

$$t_{LPG} = \cos(qL) + i\frac{\delta \sin(qL)}{q} \qquad (12) \qquad \phi_L(\omega) = \tan^{-1}\left(\frac{\delta}{q}\tan(qL)\right) \qquad (13)$$

The rate of change in phase with respect to frequency (ω) gives the delay experience by the frequency component of transmitted wave and calculated as

$$\tau_\rho = \frac{d\phi_L}{d\omega} = -\frac{\lambda^2}{2\pi c}\frac{d\phi_L}{d\lambda} = -\frac{\lambda^2}{2\pi c}\left[\frac{\left(\frac{\delta}{q}\right)\sec(qL)^2\left(\frac{dq}{d\lambda}\right) + \tan(qL)\frac{d}{d\lambda}\left(\frac{\delta}{q}\right)}{1+\left(\frac{\delta}{q}\right)^2\tan(qL)^2}\right] \qquad (14)$$

It is observed from these equations that if we choose proper physical parameters of long period grating such as grating length and magnitude of induced index change, it is possible to vary the delay experienced by the frequency components.

Now the rate of change of group delay with frequency determines the group velocity dispersion experienced by the frequency component. Thus the group velocity dispersion can be calculated as

$$D_{\rho} = \frac{d\tau_{\rho}}{d\lambda} = -\frac{\lambda}{\pi c}\frac{d\phi_L}{d\lambda} - \frac{\lambda^2}{2\pi c}\frac{d^2\phi_L}{d\lambda^2} \tag{15}$$

This equation shows the dependency of group velocity dispersion on the wavelength of incident wave inside the grating .The Wavelength component having minimum detuning would be the central wavelength λ_c of the transmission spectrum. on either side of λ_c, detuning increases in magnitude with positive or negative sign and With increasing magnitude of detuning the frequency components suffer lesser coupling to cladding region as a result maximum power flow confined to the core region. Since the group velocity in the core region is lesser than in cladding, these sideband wavelengths would suffer larger delay in propagation compared to the central wavelength, with increasing delay on both sides. This results in a positive dispersion corresponding to one band edge and negative dispersion corresponding to the other band edge. Magnitude of dispersion would depend upon the slope of the delay variation with frequency. Hence steeper the delay variation, larger would be the dispersion [11].

3. Result and Discussion

The dispersion relation of long period fiber grating exhibit an important property of LPFG known as dispersion property as seen in Figure (1), where detuning parameter δ is plotted as a function of dispersion parameter q for both uniform medium (dashed line) and a periodic medium (solid line). A figure 1 shows that, in case of uniform medium the slope is constant thus the dispersion is negligible. This dispersion is modified on introducing a grating. If the dispersion parameter lies in the range of $0 < q/\kappa < 1$ the core and cladding modes are coupled in the grating structure and are attenuated.

To study the dispersion capability of LPFG we have considered a LPFG of effective core index 1.458, effective cladding index 1.450, grating index $n_g \approx 1\times10^{-4}$ and centre wavelengths $\lambda_D \approx 1550$ nm. Figure 2 shows the delay response of this LPFG as a function of coupling strength κL for three different values of incident wavelength (a) λ = 1550 nm (b) λ = 1550.25 nm and (c) λ = 1550.50 nm. Figure 2(a) plotted at incident wavelength 1550 nm, we obtain three negative values of delay as (1) -240.6 ps at $\kappa L = 1.60$ (2) -248.55 ps at $\kappa L = 4.76$ and (3) -257 ps at $\kappa L = 7.90$ and delay ripple is suddenly jumps from positive to negative value for these values of κL and remains almost linear for other values. Figures 2(b) and 2(c) are plotted for incident wavelengths 1550.25 nm and 1550.50 nm, respectively. From these figures it is observed that the variation in delay is in positive manner having sinusoidal or stepwise nature.

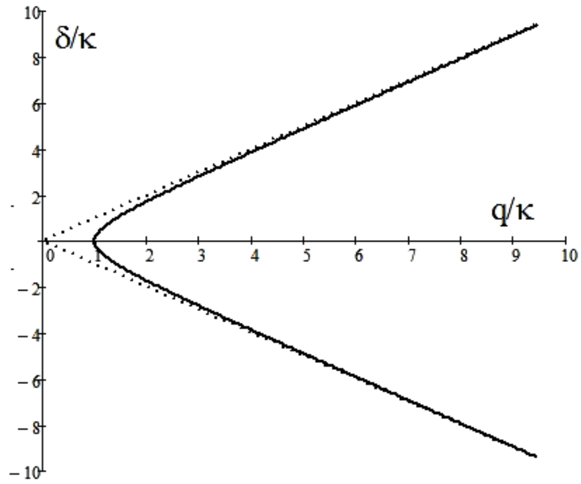

Figure 1. Dispersion curves showing variation of dispersion parameter q with detuning parameter δ

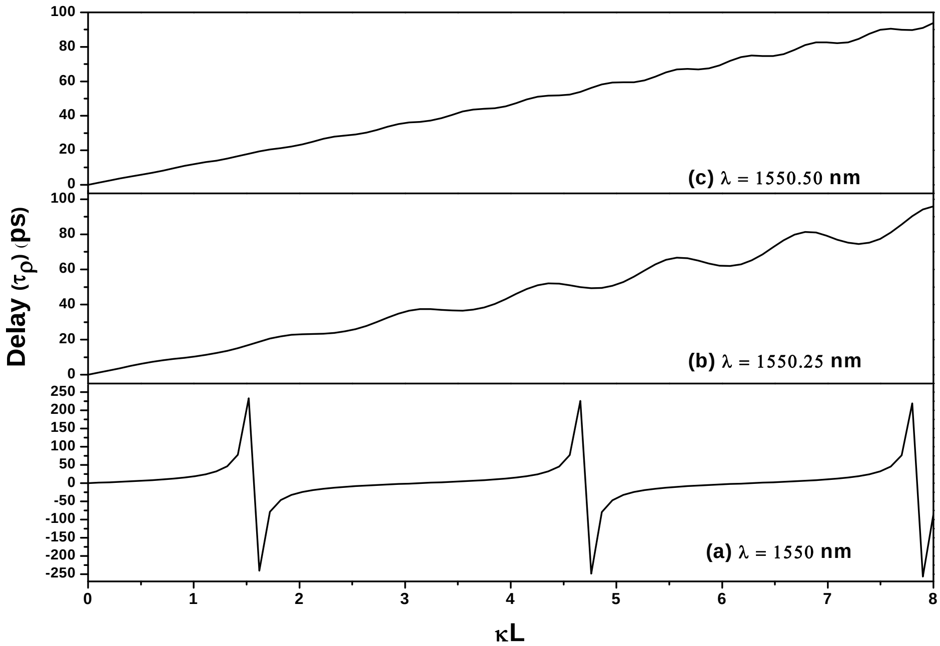

Figure 2. Delay Response of the long period gratings as a function of grating coupling strength for different values of incident wavelength (a) λ = 1550 nm (b) λ = 1550.25 nm and (c) λ = 1550.50 nm.

Above results shown that the delay becomes negative for certain values of κL = 1.60, 4.76 and 7.90 with design wavelength λ_D=1550 nm.With these physical parameter long period grating can be utilized for the application of dispersion compensation in optical communication system.

4. Conclusion

By solving coupled mode equation we have derived expressions for transmission coefficient (t_{LPG}), phase (ϕ_L), delay (τ_ρ) and group velocity dispersion (D_ρ) for proposed grating structure and the effect of grating strength on delay spectra of LPFG has been studied in detail. We have shown that, by precisely optimizing the grating length, average refractive index deviation and coupling strength of the grating, LPFG can be used as a dispersion compensating device.

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