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DC Index Shifted Dual Grating Based Superstructure Fiber Bragg Grating as Multichannel FBG and Multiparameter Sensor

Somnath Sengupta[1] and S K Ghorai[2]
[1]Department of Electronics & Communication Engineering
[2]Birla Institute of Technology, Mesra, Ranchi, India
Email: sengupta_som@yahoo.com

ABSTRACT

A new design of superstructure fiber Bragg grating using two alternately sampled FBGs is proposed. Dual-band multichannel characteristics and multiparameter sensing can be realized using multiple reflection peaks located in two separate regions of wavelength.

1. INTRODUCTION

Over the years superstructure fiber Bragg gratings (SFBG) have been playing important role in the area of optical fiber communication and sensors. The SFBGs have been widely used for dispersion compensation and multichannel characteristics with its different configurations [1-2]. High channel count comb filter based on chirped-sampled fiber Bragg grating has been reported by Y. Dai et. al. [3]. High flattened comb filter with precise channel spacing has been developed by Guodan et.al. [4]. In these structures, comb filter characteristics have been obtained within a single band of wavelengths. Recently multichannel FBG has been reported using two different DC phase shifted FBGs [5] where the multichannel characteristics is obtained only in a single band of wavelengths. So far, there is no such design which can provide multichannel characteristics in more than one wavelength range or band. The SFBG also find its application in multiparameter sensors [6-7]. The FBG and LPG loss peaks of SFBG can be used for simultaneous sensing of two or more physical parameters. Simultaneous sensing of three physical parameters is reported [8], with the use of two LPG peaks and one FBG peak out of a single band of multiple reflection peaks.

In our work, we have proposed an SFBG which can be used as a dual-band multichannel FBG as well as multiparameter sensor. In our previous work [9], we have implemented SFBG for simultaneous sensing of two physical parameters (strain and temperature). The same technique based on coupled mode equations, has been used for calculation of transmission and reflection spectra of the proposed SFBG. In our design, two FBGs with different grating period are alternately sampled with 50% duty cycle over a certain length as shown in fig.1. The two FBGs generate multiple FBG peaks at two different locations in transmission or reflection spectra. A dc index difference between two FBGs causes an LPG peak in the transmission spectra in addition to dual band FBG peaks. The two FBG loss peak bands and one LPG loss peak would allow the SFBG to act as multiparameter sensors whereas two FBG bands in reflection spectrum can provide multichannel characteristics in two different wavelength regions.

2. THEORY

The proposed structure of DC index shifted dual grating based SFBG has been shown graphically in fig.1. Two FBGs with different grating period and different dc indices are sampled periodically. The periodicity of sampling gives the period of long period grating and thus wavelength of LPG peak. Due to the sampling of FBGs, multiple reflection peaks are achieved. Hence, the reflection spectra will contain reflection spectra in two regions of wavelengths and the transmission spectra will contain loss peaks due to FBG and LPG peaks.

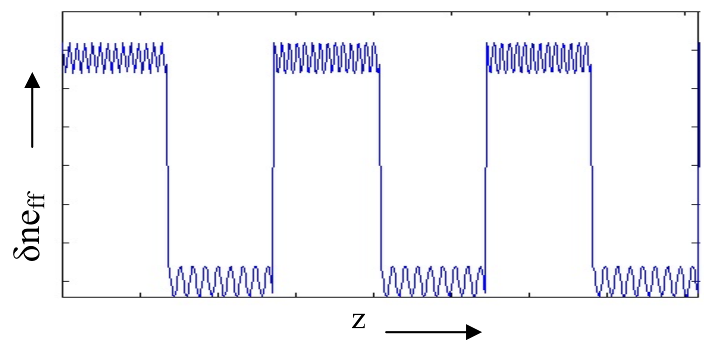

Fig.1. Refractive index variation dc index shifted dual gating based SFBG

In our approach, the coupled mode equations for a grating section can be written as [9]

$$\frac{dA}{dz} = i\sigma A + ik_s A_i e^{-2i\Delta\beta_s z} + ik_1 B e^{-2i\Delta\beta_1 z} + ik_i B_i e^{-2i\Delta\beta_i z} \quad (1a)$$

$$\frac{dA_i}{dz} = ik_s A e^{2i\Delta\beta_s z} \quad (1b)$$

$$\frac{dB}{dz} = -ik_1 A e^{2i\Delta\beta_1 z} - ik_i A_i e^{2i\Delta\beta_i z} - i\sigma B \quad (1c)$$

$$\frac{dB_i}{dz} = -ik_i A e^{2i\Delta\beta_i z} \quad (1d)$$

where A and B represent forward and backward core mode, A_i and B_i define the forward and backward cladding mode, σ is a 'DC' coupling coefficient, k_1 is an 'AC' coupling coefficient, k_i is the coupling coefficient for core mode-cladding mode contra-directional coupling, and k_s is the coupling coefficient for core-clad codirectional mode coupling.

The detuning parameters are:

$$\left.\begin{aligned}
\Delta\beta_1 &= \frac{1}{2}\left(2\beta_{co} - \frac{2\pi}{\Lambda_B}\right)\\
\Delta\beta_i &= \frac{1}{2}\left(\beta_{co} + \beta_{cl} - \frac{2\pi}{\Lambda_B}\right)\\
\Delta\beta_s &= \frac{1}{2}\left(\beta_{co} - \beta_{cl}^{1i} - \frac{2\pi}{\Lambda_S}\right)
\end{aligned}\right\} \quad (2)$$

Λ_B represents FBG period and for two different sections it will be different and Λ_S is sum of two sections representing LPG period. The differential equations have been solved by converting these into linear form and matrices for two separate grating sections have been formulated. Transfer Matrix Method has been used to calculate the transmission and reflection coefficients.

3. RESULTS AND DISCUSSION

The fiber parameters used are chosen as follows: core index n_1=1.4503, cladding index n_2=1.4450, core diameter = 8.4 µm, cladding diameter = 125 µm. The periods of two FBGs are 0.5354 µm and 0.5562 µm. The period of LPG is 545 µm. The dc and ac component of the FBG segments are 2.84×10^{-3} and 1×10^{-4} respectively. The total length of the SFBG is 2.18 cm considering 80 samples of FBG and phase shift sections of 50% duty cycle.

The transmission and reflection spectra for the proposed SFBG are shown in fig.2 & fig.3 respectively.

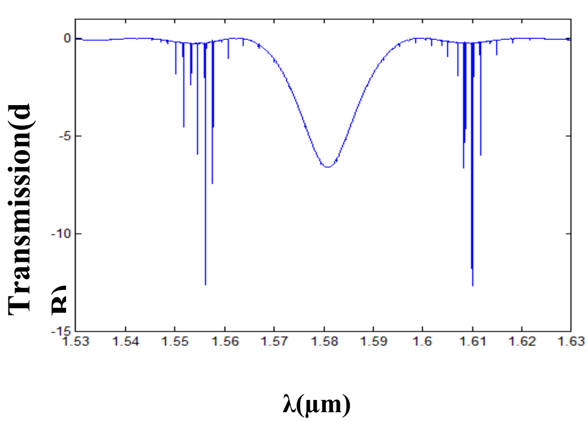

Fig.2. Transmission spectrum of dual grating based SFBG

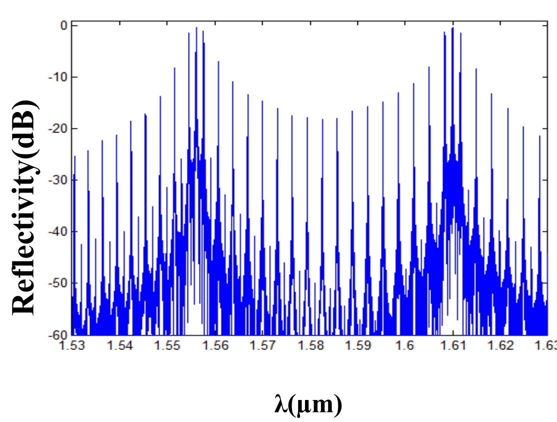

Fig.3. Reflection spectrum of dual grating based SFBG

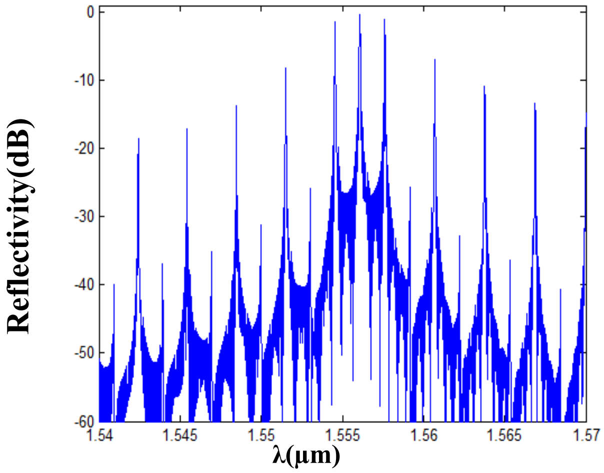

Fig.4. Reflection spectrum

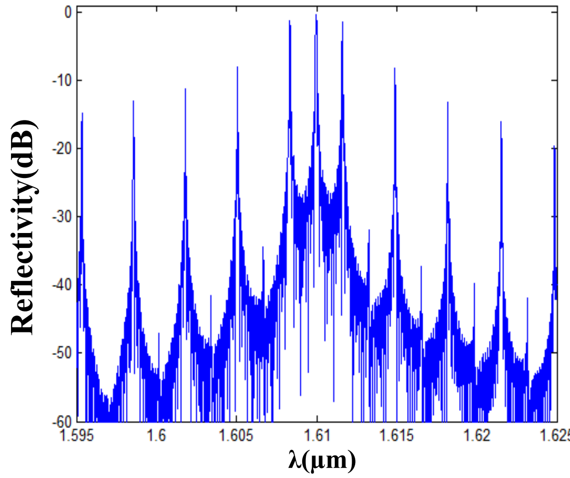

Fig.5. Reflection spectrum

The expanded view of fig.3 of reflection spectra in two different bands or wavelength range are depicted in fig.4 & 5. Multichannel characteristics have been obtained in each of these two bands which can be used as dispersion compensation for WDM channels. To use the SFBG in DWDM system, channels spacing can be decreased by introducing multiple phase shifts in the grating sections. Chirping and phase compensation can be applied on SFBG in order to obtain equal reflectivity at all channels like in the case of multichannel comb filters.

The transmission characteristics can be utilized for multiparameter sensing. The LPG loss peak and two FBG loss peaks located separately in two narrowband loss peak regions can be considered for simultaneous sensing of three physical parameters (e.g. strain, temperature & vibration etc.). From the transmission spectrum (Fig.2), The shift of the two FBG and LPG peaks due to three meaurands can be expressed as (Eq. 3)

$$\begin{aligned} \Delta\lambda_{FBG1} &= A\Delta X1 + B\Delta X2 + C\Delta X3 \\ \Delta\lambda_{FBG2} &= D\Delta X1 + E\Delta X2 + F\Delta X3 \\ \Delta\lambda_{LPG} &= G\Delta X1 + H\Delta X2 + L\Delta X3 \end{aligned} \quad (3)$$

Where variables A- L are the coefficients for three physical parameters (X1, X2, X3) for the two FBG and LPG peaks.

4. CONCLUSION

The proposed dual grating based SFBG can provide both dual-band multichannel characteristics as well as multiparameter sensing. When SFBG is to be used as dispersion compensator or multichannel FBG, the LPG peak would be undesirable if FBG peaks are located in LPG attenuation band. In that case, the dc index shift may be reduced to zero to eliminate the LPG coupling.

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