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Superstructure Fiber Bragg Grating based Sensors

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Abstract

For super structure fiber grating consisting of fiber bragg grating and long period fiber bragg grating, a similarity transformation method for the coupled mode equations is presented. The simulations show that the reflection spectrum and transmission spectrum corresponding to v-order cladding mode will shift independently with strain gradient or temperature gradient along the SFG according to a certain law. For fiber bragg grating problems, widely used theories and numerical methods such as coupled–mode theory and transfer matrix method will be applied in the analysis, modelling and simulation.

Keywords*: Superstructure fiber grating, Fiber bragg grating, Long period fiber grating, Coupled- mode theory.*

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1. Introduction

In the last few years, a growing interest has resulted in increase research projects on fiber bragg gratings in the field of fibre optics, both experimentally and numerically. Fibre Bragg gratings are very useful and powerful optical devices used in fibre optical communications and for fibre optical sensors. The potential applications of Bragg gratings are still under development. In this project we are intending to design a sensor using superstructure fibre grating for simultaneous sensing of strain and temperature. This kind of sensor will be first of its kind. We will be first simulating fibre Bragg grating using coupled mode theory. From that we will be able to determine the reflection spectra of fibre Bragg grating. Then we will determine the transmission spectra of long period gratings using coupled theory. Then we will study the theory of superstructure fiber gratings. By using similarity transformation method we will design superstructure fibre grating which will be used in simultaneous sensing of strain and temperature.

2. Literature Survey

Erdogan [1]: Advantages of fiber gratings over competing technologies include all fibre geometry, low insertion loss, high return loss or extinction, and potentially low cost. But the

most distinguishing feature of fibre gratings is the flexibility, they offer for achieving desired spectral characteristics. Numerous physical parameters can be varied, including: induced index change, length, apodization, period chirp, fringe tilt, and whether the grating supports counter propagating or co-propagating coupling at a desired wavelength. By varying these parameters, gratings can be made with normalized bandwidths between 0.1 and 10^{-4}, extremely sharp spectral features, and tailorable dispersive characteristics.

Kersey et al. [2]: Fiber Grating Sensors – The advantages of optical fibre sensing are well known and have been widely extolled in the research literature on the subject. Fibre sensors have, however, resulted in relatively few real commercial successes, and the technology remains in many instances, laboratory-based at the prototype stage. The reason for this is becoming clear to most researchers in the field: many fibre optic sensors were developed to displace conventional electro-mechanical sensor systems, which are well established, have proven reliability records and manufacturing costs. Thus, even though fibre sensors offer important advantages such as electrically passive operation, EMI immunity, high sensitivity, and multiplexing capabilities, market penetration of this technology has been slow to develop. In applications where fibre sensors offer new capabilities, however, such as distributed sensing, fibre sensors appear to have a distinct edge over the competition. Fibre Bragg gratings (FBG's) and other grating-based devices are examples of the type of sensors which provide this capability.

Zheng et al. [3]: Fibonacci Quasi-periodic superstructure fibre bragg gratings – superstructure fibre bragg grartings constructed following the Fibonacci sequence are proposed and simulated by using the transfer matrix method. The reflection spectrum has multi-faractal structure has function of the wavelength and is symmetric to the center. The reflectivity has self-similarity and scaling with respect to the Fibonacci sequence order at the central wavelength. For the transmission spectrum, the interaction of the core-cladding mode is investigated and the particular wavelength for which the resonance condition is satisfied is located by varying the grating parameters. The potential application of the quasi-periodic structure as fiber sensors is also proposed.

Zhao [4]: Simulation program for fibre bragg grating – For fibre bragg grating problems, widely used theory and numerical methods such as the coupled-mode theory and transfer matrix method will be applied in the analysis, modelling and simulation. The coupled-mode theory is a suitable tool for analysis and for obtaining quantitative information about the spectrum of fibre bragg grating. The transfer matrix can be used to solve non-uniform fibre bragg gratings. Two coupled mode equations can be obtained and simplified by using the weak wave guide approximation. The spectrum characteristics can be obtained by solving these coupled-mode equations.

3. Methodology

In this process we used MATLAB for the purpose of simulation. The coupled-mode theory (CMT) was used for basis of mathematical calculations. By the help of this sensor strain and temperature were calculated and by using different values for strain and temperature results are verified successfully. So superstructure fibre bragg grating sensors or FBGs sensors can be used to measure strain and temperature.

4. Result and Discussion

Simulation Results:

Reflection Spectra of SFG with different Strain and Temperature

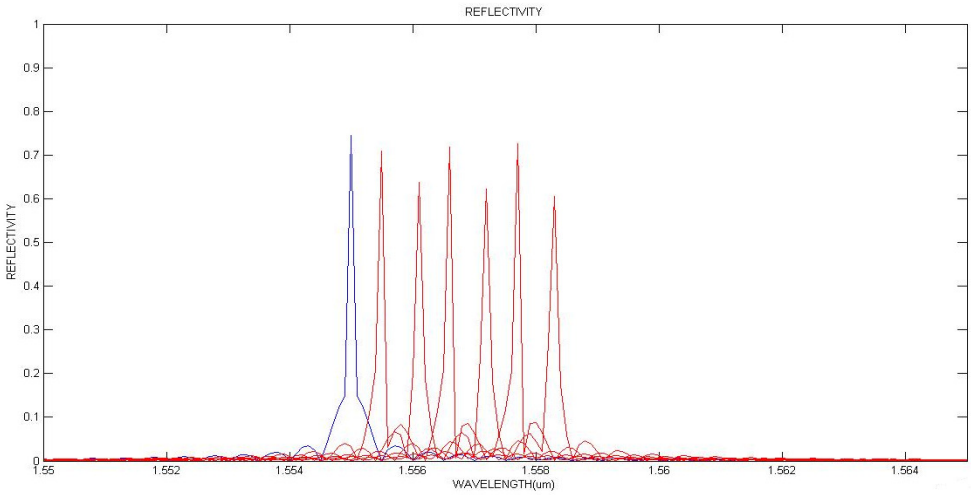

Fig. 1: Reflection Spectrum of Superstructure Fiber Bragg Grating when various Strain (from 0.2 Millistrain to 2 Millistrain) and Temperature (from 30.C to 90.C) is applied. The blue graph is the transmission spectra when no strain and temperature is applied while the red graphs are the one when various strains and temperatures are applied. (The parameters for the above can be found in the section 'Parameters used'). The centre frequency is 1550.2nm for the FBG peak and 1580nm for the LPG peak. The shifted wavelength can be found using spectrum analyser.

Effect of various Strain on Transmission Spectra of SFG

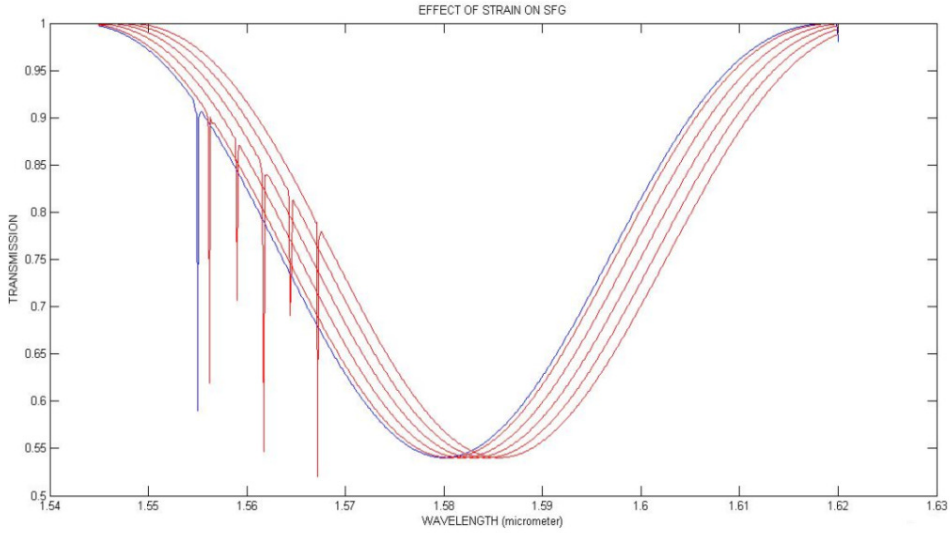

Fig. 2: Transmission Spectrum of Superstructure Fiber Bragg Grating when various Strain (from 0.2 millistrain to 2 millistrain) is applied. The blue graph is the transmission spectra when no strain is applied while the red graphs are the one when various strains are applied. (The parameters for the above can be found in the section 'Parameters used'). The centre frequency is 1550.2nm for the FBG peak and 1580nm for the LPG peak. The shifted wavelength can be found using spectrum analyser.

Table: Strain and Temperature Coefficients Parameters

SN	Strain and Temperature Coefficients	Values	Unit
1	A=$\Delta\lambda FBG/\Delta\epsilon$	1.2454	nm/millistrain
2	B=$\Delta\lambda FBG/\Delta T$	.5722	nm/^{o} C
3	C=$\Delta\lambda LPG/\Delta\epsilon$	9.18*10^-3	nm/millistrain
4	D=$\Delta\lambda LPG/\Delta T$	42*10^-3	nm/^{o} C

5. Future Scope

- *Applications to large composite and concrete structures*: When compared with traditional electrical strain gauges used for strain monitoring of large composite or concrete structures, FBG sensors have several distinguishing advantages, including (i) much better invulnerability to electro-magnetic interference, including storms, and the potential capability of surviving in harsh environments, such as in nuclear power plants; (ii) much less intrusive size (typically 125 lm in diameter * ideal size for embedding into composites without introducing any significant perturbation to the characteristics of the structure); (iii) greater resistance to corrosion when used in open structures, such as bridges and dams; (iv) greater capacity of multiplexing a large number of sensors for strain mapping along a single fibre link, unlike strain gauges which need a huge amount of wiring; (v) higher temperature capacity (typically & 3003 C).
- *Applications in the electric power industry*: Like other implementations of fibre-optic sensors, FBGs are ideal for use in the electrical power industry due to their immunity to electro-magnetic interference. In addition, FBGs can be written onto standard 1.55 lm wavelength telecommunication fibre, hence long-distance remote operation is feasible due to the low transmission loss of the fibre. Loading of power transmission lines, winding temperature of electrical power transformers and large electrical currents have been measured with the FBG sensor. The applications are as follows (a) Load monitoring of power transmission lines (b) Winding temperature measurement (c) Electric current measurement.
- *Applications to medicine*: The majority of commercial sensors widely used in medicine is electrically active and hence they are not appropriate for use in a number of medical applications, in particular, in high microwave/radio-frequency fields or ultrasound fields or laser radiation associated with hyperthermia treatment, due to local heating of the sensor head and the surrounding tumor due to the presence of metallic conductors and electro-magnetic interference of currents and voltages in the metallic conductors, resulting in erroneous readings. Fibre-optic sensors can overcome these problems as they are virtually dielectric. A range of miniature fibre-optic sensors based on intensity modulation have been successfully commercialized in recent years. Generally speaking, these sensors are all point sensors which can only provide readings over a small volume in the human body.
- *Applications to chemical sensing*: The FBG sensor [5, 6] can also be used for chemical sensing based on the fact that the central wavelength of an FBG varies with refractive index change, i.e. chemical concentration change, via the evanescent field interaction between the FBG and the surrounding chemical. An approach based on an FBG written onto an etched D-fibre has been demonstrated and very recently a modified version based on a side polished fibre configuration has been reported as a refractive index sensor, allowing fast on-line

measurements of chemicals, such as carbon hydrides in petrol industry. Because of the constraint of current interrogation techniques with a typical resolution of 1 pm for static wavelength-shift measurement, the sensitivity obtained is much lower (up to 10~5) compared with other fibre-optical techniques, e.g. the interferometric method with a sensitivity of up to 10~8. A new type of fibre grating called long-period grating (LPG) has been discovered to be more sensitive to the refractive index change of the material around the grating cladding when compared with FBGs.

6. Conclusion

We simulated a sensor based on superstructure fiber bragg grating which very effectively responded to strain and temperature variations. In the process we used Coupled-mode theory as our basis in order to study the transmission and reflection spectra of Superstructure fiber bragg grating. We use MATLAB in order to simulate the various mathematical condition derived by us and thus we are able to get our desired results.

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