Response of fiber Bragg grating transmission dips at twice the Bragg wavelength to transverse strain

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ABSTRACT

The effect of transverse strain on a fiber Bragg grating fabricated using a phase mask with 536-nm pitch has been investigated through the study of its reflection and transmission features at twice the Bragg wavelength near 1552 nm, that are due to reflection/transmission from FBG periodicities associated with the phase mask periodicity. The occurrence of two peaks in the reflection spectrum is due to the interleaved refractive index modulations along the fiber core, with the periodicity of the phase mask that produces a type of $\pi$-phase-shifted grating. The response of these features to transverse strain is similar to that observed previously for features at $2/3$ of the Bragg wavelength that also arise from the same complex refractive index structure.

Keywords: Fiber Bragg grating (FBG) sensor, $\pi$-phase-shifted grating, transverse strain

1. INTRODUCTION

The reflective and transmissive properties of fiber Bragg gratings (FBGs) have been well studied and used in many applications\textsuperscript{1}. Usually their fabrication requires use of a UV laser beam that is directed through a phase mask, of period $\Lambda_{pm}$; the resultant interference pattern induces a refractive index variation along the fiber core\textsuperscript{2,3}. The Bragg wavelength, $\lambda_B$, is the first harmonic resonance (i.e. $m = 1$) given by [1]:

$$\lambda_B(m) = \frac{2}{m} n_{eff} \Lambda,$$

where $\lambda_B(m)$ is the reflected wavelength at the harmonics $m = 1, 2, 3, \ldots$, $n_{eff}$ is the effective index of the fundamental fiber mode and $\Lambda$ is the grating period along the fiber core. Phase masks are designed to provide maximum contrast for the interference of the $\pm 1$ diffraction orders. However, a real phase mask also has zero and higher diffraction orders present and this results in co-existing periods of $\Lambda = \Lambda_{pm}/2$ and $\Lambda_{pm}$ in a FBG\textsuperscript{4-7}. Indeed, these have been imaged using differential interference contrast (DIC) microscopy\textsuperscript{8} and the formation of the complex refractive index structure observed has been verified by modeling based on the strengths of the diffraction orders of the phase mask used\textsuperscript{9}. Spectral features of FBGs at shorter wavelengths, corresponding to higher (i.e. $m > 1$) harmonic reflections in Eq. (1) with $\Lambda = \Lambda_{pm}/2$ have been reported\textsuperscript{3}, e.g. at 770 nm. Features at 620 and 1030 nm, on the other hand, are due a grating having the phase mask period (i.e. $\Lambda = \Lambda_{pm}$), in which these are the $m = 5$ and 3 orders, respectively\textsuperscript{3,10}. The fundamental reflection (i.e. $m = 1$) for the $\Lambda = \Lambda_{pm}$ periodicity has been observed and it was shown that the standard phase mask technique produced an alternative type of $\pi$-phase-shifted grating at twice the design Bragg wavelength\textsuperscript{11}.

Fiber Bragg gratings exhibit a sensitivity to transverse strain in addition to longitudinal strain and temperature. In non-birefringent fiber, transverse strain causes the Bragg peak to split slightly, due to induced birefringence\textsuperscript{12}. For FBGs inscribed in birefringent fiber, the pair of closely spaced Bragg wavelengths separates further when transverse strain is applied\textsuperscript{13}; use of two FBGs with different periodicities produces 4 separate Bragg peaks, enabling the measurement of all
three strain directions and temperature, simultaneously. Transverse strain measurement has also been demonstrated using long period gratings\textsuperscript{14}, π-phase-shifted gratings\textsuperscript{15} and superstructure gratings\textsuperscript{16}. Previously we had reported on the effect of transverse strain on features in FBG spectra at 2/3 of the Bragg wavelength\textsuperscript{17}, which are now understood\textsuperscript{11} to be the 3\textsuperscript{rd} harmonic of a grating with $\Lambda = \Lambda_{\text{pm}}$, in which the response depends upon the fiber orientation\textsuperscript{18}. Through the use of a phase mask having periodicity of 536 nm the effect of longitudinal strain and temperature on a grating operating near 1550 nm, which is twice the design Bragg wavelength and the fundamental reflection arising from $\Lambda = \Lambda_{\text{pm}}$ have been investigated\textsuperscript{19}. In this work we report on the behavior near 1550 nm of a similar grating (i.e. having $\lambda_B$ at 785 nm) when it was subjected to transverse strain.

2. EXPERIMENTAL DETAILS

The setup for investigating the response at twice the design Bragg wavelength to transverse strain is similar to that used previously\textsuperscript{17}, which enabled the transverse strain applied to the grating to be varied by changing the loading of the weights and which prevented longitudinal strains from occurring. The FBG was fabricated in Corning 1060 nm fiber using a 244-nm UV continuous laser source through a phase mask of periodicity 536 nm. The fiber was pre-processed with hydrogen to increase the photosensitivity. FBG reflection spectra were obtained with an Ando optical spectrum analyzer, following illumination by an erbium broadband source. Weights of up to 5.5 kg were applied to the apparatus.

3. RESULTS AND DISCUSSION

The changes in FBG transmission spectra in response to the applied load on the grating are illustrated in Fig. 1.

![Fig. 1. Examples of transmission spectra at twice the Bragg wavelength for different applied loads, showing the splitting of one peak.](image-url)
In Fig. 1(a), for which no external transverse strain is applied, two clear peaks are present in the reflection spectrum that arise from the π-phase-shifted grating produced through the use of the phase mask technique. There were no significant spectral transformations until 3000 g was applied. As the applied load increased, the details of the spectrum began to change, including the splitting of the lower wavelength peak as evident in Fig. 1(b) and Fig. 1(c). This alteration of spectra, including the splitting of one of the peaks is consistent with data obtained at 2/3 of the Bragg wavelength, for which the two peaks correspond to the 3rd harmonic of a grating periodicity equal to that of the phase mask.

The splitting of the lower wavelength peak, indicated by the arrows in Fig. 1, against the applied load is presented in Fig. 2. The separation of the two dips increased linearly with applied strain and the fitted slope was 0.04 nm/kg, which is consistent with the effect reported at 2/3 of the Bragg wavelength, but which is also believed to be dependent on the orientation of the fiber.

4. CONCLUSION

The behavior of the 2 peaks that occur at twice the Bragg wavelength (i.e. near 1550 nm in this case) in the reflection spectrum of a type of π-phase-shifted FBG, produced very simply using the phase mask method of FBG writing, when it was subjected to transverse strain, has been investigated. The grating had a design Bragg wavelength of 785 nm, and was written into a fiber that is single-mode. Transverse strain caused one of the peaks to split into two components, with the wavelength separation being directly proportional to the applied transverse strain, in a manner that was consistent with previous measurements at 2/3 of the Bragg wavelength. The advantage of using the π-phase-shifted FBGs employed here, that arise from the interleaved refractive index modulations along the fiber core having the periodicity of the phase mask, is that they are much easier to fabricate compared with normal π-phase-shifted FBGs.

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6. REFERENCES