Occurrence of Features of Fiber Bragg Grating Spectra Having a Wavelength Corresponding to the Phase Mask Periodicity

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Abstract—Use of a phase mask with 536 nm uniform pitch allowed the fabrication of a fiber Bragg grating for use at a Bragg wavelength of 785 nm. Reflection and transmission features at 1552 nm, i.e. twice the Bragg wavelength, associated with the phase mask periodicity were observed. However, when phase mask orders other than ±1 were absent during fabrication the features at 1552 nm were not evident.

Index Terms—fiber Bragg grating, double of the Bragg wavelength, phase mask, Talbot interferometer.

1. Introduction

The fiber Bragg grating (FBG), as an in-line optical filter, has found many applications in communications and sensing[1]. Reflection peaks or transmission dips in a particular wavelength region due to the $m$th harmonic resonance associated with a periodic refractive index variation is described by the well-known formula,

$$\lambda_{m(A)} = \frac{2}{m} n_{\text{eff}} A,$$  \hspace{0.5cm} (1)

where $\lambda_{m(A)}$ is the reflected wavelength of order $m = 1, 2, 3, \ldots$, $n_{\text{eff}}$ is the effective index of the fundamental mode of the core at $\lambda_{m(A)}$ and $A$ is the FBG period. When an FBG is fabricated with a phase mask the FBG periodicity is half that of the phase mask period (i.e. $A = \Lambda_{\text{pm}}/2$).

Various authors have reported the observation of higher FBG diffraction orders in agreement with (1). In particular, a phase mask with 1060 nm pitch that produced a Bragg wavelength at 1535 nm, had a transmission dip at 770 nm[2], which is the second order ($m = 2$) of a grating having a periodicity of half that of the phase mask, as expected. However, other responses at 620 and 1030 nm[3][4] can only be explained by the existence of a grating with the phase mask period (i.e. $A = \Lambda_{\text{pm}}$), in which these are the $m = 5$ and 3 orders, respectively. Such a grating is thus expected to have features near 3 μm, which is inaccessible with conventional optical fiber technology. Simulations and experiments concerning phase mask properties have shown that the co-existing periods (i.e. $A = \Lambda_{\text{pm}}/2$ and $\Lambda_{\text{pm}}$) in a FBG are due to the interference of the non-suppressed zeroth and higher diffraction orders of the phase mask[5]. Furthermore, differential interference contrast imaging[6] and other imaging methodology[7], has revealed that FBGs fabricated by the standard phase mask technique have a complex structure within, exhibiting these two separate grating periodicities (i.e. $A = \Lambda_{\text{pm}}/2$ and $\Lambda_{\text{pm}}$).

For further confirmation of the existence of a grating having the same periodicity as that of the phase mask (i.e. $A = \Lambda_{\text{pm}}$), observation of spectral responses due to the $m = 1$ harmonic of such a periodicity is required. Clearly, to achieve this, a much smaller phase mask periodicity is required, to avoid the high optical fiber attenuation at wavelengths greater than 1550 nm.

This paper describes how a phase mask having a uniform pitch of 536 nm was illuminated by an UV laser beam to fabricate a FBG having a Bragg wavelength near 785 nm. The peaks and dips in reflection and transmission spectra near 1550 nm, that are at twice the Bragg wavelength and are associated with a grating with the phase mask periodicity (i.e. $A = \Lambda_{\text{pm}}$), were studied. It is further reported how the experimental arrangement allowed relocation of the fiber position without having to re-align any other component. This modification of a standard phase mask arrangement provided a Talbot interferometric set-up so that the effect of the presence or absence of diffraction orders of the phase mask other than ±1 on spectral properties (i.e. peaks or dips) at twice the Bragg wavelength could be investigated.

2. Experiment

2.1 Schematic diagram

The experimental set-up is shown in Fig. 1. A collimated 130 mW UV laser beam was used to fabricate FBGs in Corning 1060 nm fiber (numerical aperture 0.14,
cutoff wavelength 920 nm) through a phase mask with 536 nm uniform pitch. The fiber was exposed to 92 atm of hydrogen at 65 °C for 3 days to increase the photosensitivity prior to irradiation. The hydrogenated fiber was located at position 1, i.e. within tens of micrometers from the phase mask to ensure exposure of the fiber to the interference pattern generated by all diffraction orders. The relative strengths of the diffraction order of the phase mask were measured, and the average percentage distribution of the 0, ±1 and ±2 orders were 9.8%, 34.6% and 7.2%, respectively.

The behavior of transmission and reflectance spectra near 1.55 nm (corresponding to \( \lambda_{(A_{pm})} \)) were monitored by an optical spectrum analyzer (OSA), connected to a computer, using illumination by an Er^3+ broadband source. A 780 nm centre wavelength superluminescent laser diode of FWHM = 45 nm was used to analyse the reflection and transmission spectra in the region of \( \lambda_{(A_{pm})} \) (i.e. near 785 nm) by the same OSA. A Corning 3 dB coupler configuration with a 1060 nm operation wavelength was used so as to minimize the power loss in the range from 0.78 to 1.5 \( \mu \)m.

2.2 FBG writing with ±1 phase mask orders only

Secondly, through the reflection from the pair of mirrors, the +1 and -1 diffraction orders of the phase mask were recombined and to form pure first-order interference within a fiber when it was located in position 2 (in Fig. 1), in a Talbot interferometer set-up. Illumination times for position 2 were slightly longer than for position 1 (12 and 8 min, respectively). This provided compensation for the lower overall irradiance at position 2 for which only the ±1 diffraction orders were present. The fiber could be relocated easily between the two fabrication positions without adjustment of the optical components, thereby ensuring that any differences between FBGs fabricated in these positions would be due only to the change in the fiber position.

3. Results and Discussion

3.1 Spectral features obtained with position 1.

A clear single transmission dip at \( \lambda_{(A_{pm})} \) is observed at 784.9 nm as shown in Fig. 2(a) and the corresponding single peak reflectance at the same wavelength is greater than 75% of the incident power, as shown in Fig. 2(b). The slight energy loss in the reflection spectrum may be due to cladding mode scattering from the FBG. This dominant reflectance/transmission at \( \lambda_{(A_{pm})} \) is attributed to a FBG having a grating periodicity in the fiber core equal to \( A_{pm}/2 \), which arises from exposure to the UV interference of the +1 and -1 diffraction orders of the phase mask.

![Fig. 1 Schematic for controlling diffraction orders of the phase mask for fabricating FBGs in position 1 and 2.](image)

![Fig. 2 Examples of FBG spectra at \( \lambda_{(A_{pm}/2)} \); (a) transmittance and (b) reflectance, for the FBG fabricated in position 1.](image)

Fig. 3 shows that there were two transmission dips and reflection peaks at \( \lambda_{(A_{pm})} \) at 1552.2 and 1552.5 nm, respectively. The reflectances of the two peaks shown in Fig. 3(b) are over 0.22, with about 3 nm separation and less than 6% variation. These spectra are attributed to the interference pattern created by the interference of the zeroth and higher order diffraction orders generated with a period equal to the phase mask \( (A_{pm}) \), as explained previously. The occurrence of a pair of reflection peaks/transmission dips is still being investigated; they are believed to be associated with a slight asymmetry in the experimental arrangement.
fiber to be irradiated at one of two positions. The experimental arrangement enabled a fiber to be irradiated at one of two positions, with the fabrication setup being either the standard phase mask arrangement (fiber at position 1) with all phase mask diffraction orders present, or an interferometric setup (fiber at position 2) that ensured that only the ±1 orders were present. While both arrangements produced FBGs having a Bragg wavelength in the 785-nm region (with similar transmittance), only the first arrangement produced a transmission dip in the transmission spectrum at around 1550 nm, which is due to the first harmonic of a grating having a period equal to the phase mask period. The result is consistent with previous experiments and it shows that features at twice the Bragg wavelength arise during FBG fabrication because of the existence of phase mask diffraction orders in addition to the ±1 orders.

3.2 Spectral features obtained with position 2.

When a FBG was fabricated with the fiber in position 2, spectra were obtained in the same regions as before, i.e. 785 and 1555 nm; these are shown in Fig. 4(a) and (b). The clear transmission dip observed at 788.1 nm (i.e. the Bragg wavelength) has 80% transmittance. However in the scan of the spectrum from 1520 to 1570 nm, there is no evidence of any transmission dips whatsoever. Given that in position 2 the UV light had only ±1 diffraction orders, this is clear evidence that the response at double of the Bragg wavelength is due to the existence of diffraction orders in addition to ±1, as illustrated by the FBG fabricated when the fiber was located in position 1. The non-uniform transmittance observed in the higher wavelength region (less than 10% variation in transmittance) may be due to the polarization difference between the set-up for measuring the transmission of FBG and the spectrum of the input broadband source.

4. Conclusions

A FBG having dual-grating periodicities generated by the first-order diffraction wavelengths at \( \lambda_{1(Apm)} \) and \( \lambda_{1'(Apm)} \), was fabricated by a phase mask with uniform pitch (536 nm) using the standard FBG writing technology. The observation of spectral features at double of the Bragg wavelength (i.e. 1550 nm) confirms the existence of a grating period equal to the phase mask periodicity. The experimental arrangement enabled a

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References


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