# Optical inclinometer based on phase-shifted Bragg grating in a taper configuration

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## ABSTRACT

A simple optical inclinometer based on phase-shifted Bragg grating in a taper configuration is proposed. The phase-shifted FBG was fabricated using a DUV femtosecond laser technique in the taper region. The sensing head was characterized for different angle curvatures and also to strain. The angle and strain sensitivities of the inclinometer are 13.15 pm/degree and 8.96 pm/με.

**Keywords:** optical fibre sensors, Fibre Bragg Grating, taper.

## 1. INTRODUCTION

Most fibre Bragg gratings (FBG) designed for practical applications are non-uniform gratings structures. Often the main reason for choosing a non-uniform design is to reduce the undesirable side lobes prevalent in uniform-grating spectra. To achieve that, several techniques can be used. Besides spectral response, there are many other reasons to adjust the optical properties of fibre gratings by tailoring the grating parameters along the fibre axis. Sharp, well-defined filter shapes are rapidly becoming critical characteristics for passive components in dense wavelength division multiplexed (DWDM) communications systems. On the other hand, chirping the period of a grating enables the dispersive properties of the scattered light to be tailored [1]. Sometimes it is desirable to create discrete, localized phase shifts in an otherwise periodic grating. Discrete phase shifts can be used to open an extremely narrow transmission resonance in a reflection grating or to tailor the passive filter shape. The principle of the phase shift was demonstrated by Alfemess *et al.* [2] in periodic structures made from semiconductor materials, where a phase shift was introduced by etching a space at the centre of the device. This forms the basis of the single-mode phase-shifted semiconductor DFB laser [3]. A similar device may be constructed in optical fibres using various techniques. Such processing produces two gratings out of phase with each other, which act as a wavelength-selective Fabry-Pérot resonator. The resonant wavelength corresponds to a transmitting filter over the rejection band of the Bragg grating and depends on the amplitude and location of the phase change. The resonant wavelength of this filter can be tuned over the spectral response of the Bragg grating by introducing one or several phase shifts within the range [0-2π] in particular locations along the grating length [4]. This technique allows the exploitation of Bragg gratings spectral response in transmission that can be used for specific applications, namely, in communication and sensing.

In terms of optical sensing, phase-shifted FBGs have been used to measure parameters such as vibration [5], strain [6] and pressure [7,8] with increased sensitivity in relation to conventional FBG systems.

In this work, the authors present an optical inclinometer based on phase-shifted Bragg gratings in a taper topology. The phase-shifted FBG is fabricated through DUV femtosecond laser technique in the taper region. The sensing head is characterized for different angle curvatures and also to strain.

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## 2. FABRICATION AND CHARACTERIZATION

To develop the phase-shifted FBG-based sensing head, a 2 mm-width slit was placed on a translation stage with the adjustable mirror in a conventional FBG fabrication setup based on the DUV femtosecond laser technique to perform a 2.5 mm displacement between FBGs inscription. The phase-shifted FBG was based on two FBGs written in the waist section of a tapered single-mode fibre with 30 μm diameter. The phase-shifted FBG presents a high reflectivity, with eight peaks separated 0.3 nm, each with a FWHM of 0.2 nm. The spectral response of the phase-shifted FBG is depicted in Figure 1. In the same figure the spectral response of a single FBG written in a taper is also presented. Both structures have a similar envelope FWHM of 1 nm.

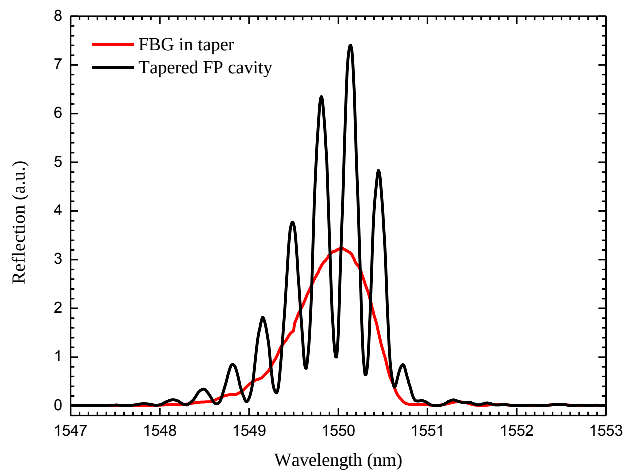


**Figure 1** – Optical spectra of a phase-shifted FBG inscribed on a tapered single mode fibre with 30 μm taper waist diameter.

## 3. RESULTS AND DISCUSSION

A 100 nm broadband source centred at 1550 nm was used, while an optical spectrum analyser (OSA) with a maximum resolution of 0.01 nm performed the sensor interrogation. An optical circulator device was used to analyse the reflection response of the optical inclinometer. To measure the relationship between the angle curvature and the peak wavelength, the inclinometer was set on a rotating platform with an uncertainty of 0.5 degrees. One end was stuck to a fixed position while the other was rotated between 0 and 90 degrees. The scheme of this setup can be seen in Figure 2.

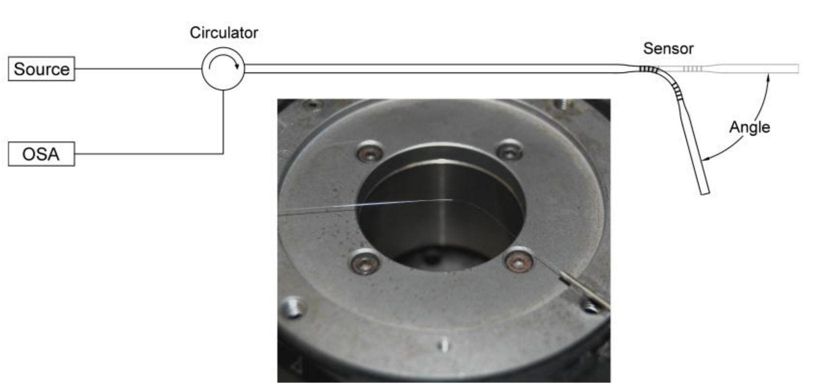


**Figure 2** – Scheme of the angular curvature characterization setup and detailed photo of the bent inclinometer.

The inclinometer was interrogated in steps of 5 degrees. The results can be seen in Figure 3. The increasing curvature of the inclinometer deforms the taper, an effect that alters the phase-shifting FBG properties. In particular, the inclinometer shows a linear dependency of the peak wavelength on the angular curvature between 45 and 85 degrees with sensitivity of 13.15 pm/degree.

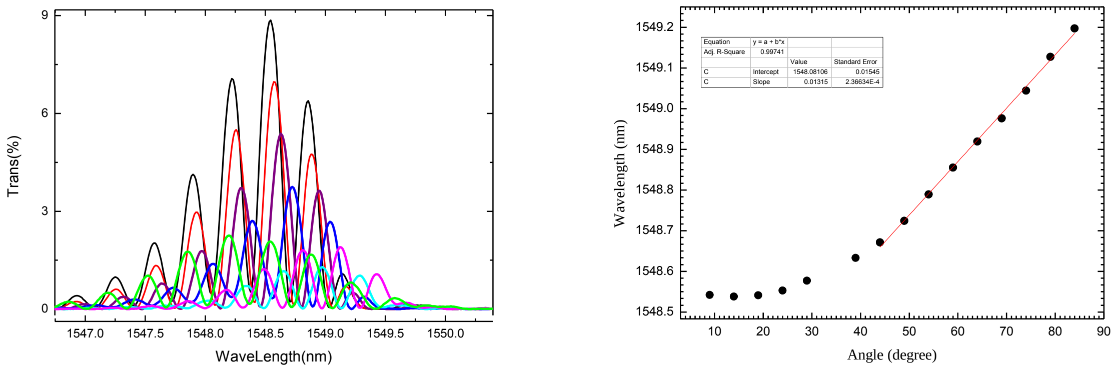


**Figure 3** – Spectral response of the sensing head subjected to different angles (left) and relationship of the wavelength response to the angle of the inclinometer (right).

For strain characterization, the sensing head was placed on micrometric translation stages to control the subjected stretching. The strain sensitivity is 8.96 pm/με, which is higher when comparing with conventional FBG [9]. See Figure 4. This result is expected due to the large asymmetry between the cross-section area of the taper and the standard diameter of the SMF28.

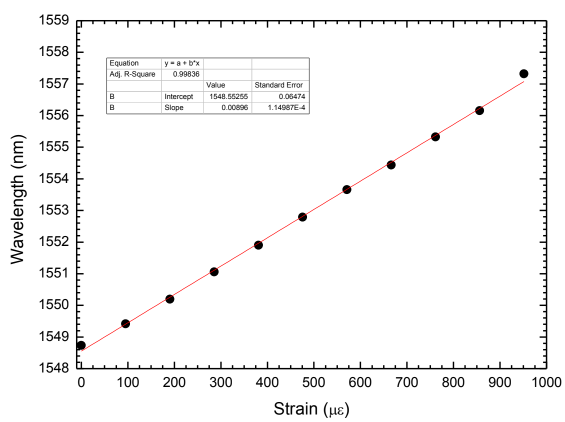


**Figure 4** – Strain response of the sensing head.

## 4. CONCLUSIONS

Summarizing, an optical inclinometer based on phase-shifted Bragg grating in a taper topology was demonstrated. The phase-shifted FBG was fabricated using a DUV femtosecond laser technique. To increase the sensitivity the phase-shifted FBG was written in a taper region. The sensing head was characterized to different angles and presented a sensitivity of 13.15 pm/degree. When strain was applied to the sensing head a sensitivity of 8.96 pm/με was obtained.

## ACKNOLEDGMENTS

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