All-fiber loading sensor based on 45° and 81° tilted fiber gratings

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ABSTRACT

We experimentally demonstrated an all fiber loading sensor system based on a 45°- and an 81°-tilted fiber grating (TFG). We have fabricated TFGs with tilted structures at 45° and 81° consecutively in one fiber. When the transverse load applied to the 81º-TFG, the light coupling to the two orthogonally polarized peaks will interchange from each other, which provides a solution to measure the load. We further investigated the all fiber loading sensor system using a single wavelength source and a power meter. The experimental results clearly show that a low-cost high-sensitivity loading sensor system can be developed based on the proposed TFG configuration.

Keywords: Optical fiber, all fiber sensor system, tilted fiber grating, loading sensor.

1. INTRODUCTION

Fiber gratings have been exploited as optical fiber sensors for measuring transverse loads due to their small size, lightness, long-term stability, immunity to electric–magnetic interference and most of all, the multiplexing capability for sensor network. Transverse load sensors based on fiber Bragg gratings (FBGs) and long period gratings (LPGs) made in low-birefringence and hi-birefringence fiber have been reported [1-4]. To function as loading sensors, the majority of these gratings exhibited a pronounced polarization mode split effect resulting from the birefringence induced by the transverse loading.

Tilted fiber gratings (TFGs) were firstly reported by Meltz *et al* [5]. Zhou *et al* [6] demonstrated high polarization extinction ratio in-fiber polarizers based on 45°-TFG structure. Detailed experimental investigation and theory analysis on large angle TFGs have also been reported [7] by Zhou *et al* . Due to the inherent polarization mode splitting effect of such gratings resulting from their tilted structures, a novel in-fiber directional transverse loading sensor based on 81°-TFG [8] has been experimentally demonstrated. However, such a sensor system requires extra polarizer and polarization controller which represents a more complex, bulky and high cost system.

In this paper, we reported an all-fiber loading sensor system, which incorporates a 45°-and an 81°-TFG in a single piece of fiber. In this system, the necessity of polarization controller is removed and the 45°-TFG is functioning as a linear polarizer which ensures the polarized light launching to the 81°-TFG, thus providing a simple solution to measure the transverse load.

2. THEORY AND FABRICATION OF TFGS

TFGs are capable of coupling the light from forward-propagating core mode to backward-propagating, radiation and forward-propagating cladding modes when the tilt angle at <45°, =45° and >45°, respectively. It is pointed out that the strongest coupling wavelength for TFGs can be given by the phase matching condition:

$$\lambda_{strongest} = (\mathrm{n}_{co} \pm \mathrm{n}_{cl,m}) \times \frac{\Lambda_G}{\cos\theta}$$

Where n_{co} and $n_{cl,m}$ are the effective refractive index of core mode and mth cladding mode, Λ_G is the grating period along the fiber and θ is the tilt angle of structure.

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In the work reported in this paper, the 45°- and 81°-TFG were UV inscribed in Corning SMF-28 fiber using the scanning mask technique. The SMF-28 fiber was hydrogen loaded at 150 bars at 80°C for 48 hours prior to the UV exposure to enhance the photosensitivity. The 45°-TFG was firstly UV-written in a 50 cm long fiber using a phase-mask with a uniform period of 1800nm and 33.7° tilted pattern on the glass substrate, which was designed for obtaining the 45° tilted structure in the fiber with polarization response at around 1550nm region._The tilted pitch pattern in the phase-mask is 25 mm long, thus, the effective length of 45º-TFG is around ~25mm. Figure 1 (a) shows the polarization dependent loss (PDL) spectral response of the 45°-TFG which was measured by using a commercial optical analysis system (LUNA optical vector analyzer). It can be seen from the figure that PDL is about 15 dB around wavelength 1550nm. The 12 mm-long 81°-TFG was then UV inscribed adjacent to the 45°-TFG in the same SMF-28 fiber using a commercial amplitude mask with a period of 6.6 μm and the mask was rotated at 76.5° to induce 81° tilted structure in the fiber core. The measured transmission spectrum of 81º-TFG shows a series of paired loss bands, corresponding to the two sets of coupled cladding modes with orthogonal polarization states [7]. Figure 1 (b) shows the transmission spectra of one of the paired peaks for two (labelled as P1 and P2) orthogonally polarized states. As shown clearly in the figure, when the grating was probed with randomly polarized light, the two peaks show similar strength, e.g. 3-dB transmission loss; while when it launched with orthogonally polarized lights (P1 or P2), one of the dual peaks grows to its full strength (~11 dB) whereas the other almost disappears.

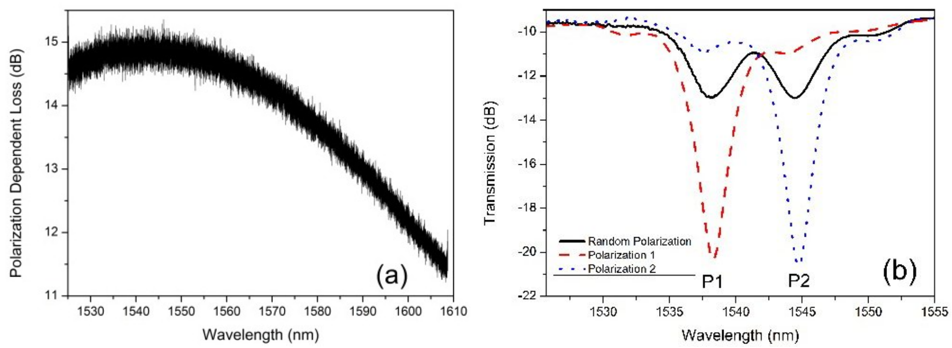
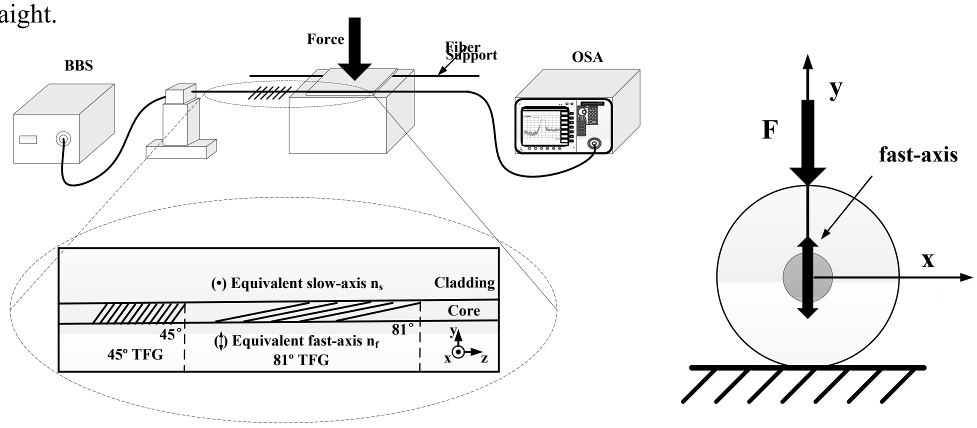


Figure 1 (a) The PDL spectral response of the 45°-TFG. (b) The transmission spectra of 81°-TFG with one pair of the dual peaks for two orthogonally polarized states and randomly polarized state.

3. EXPERIMENTAL SET UP FOR LOADING AND RESULTS

3.1 Experimental set up of loading sensor system based on 45° and 81° TFGs and loading induced spectral evolution

The experimental setup of the optical loading sensing system is illustrated in Figure 2. The light from a broadband source (BBS) was launched into the 45°-TFG to be polarized before entering the 81°-TFG and the output was monitored from the other fiber end by an optical spectrum analyzer (OSA). The 81°-TFG was laid between two flat-surface aluminum plates with a dummy fiber for balance. The active loading length between the two plates is 32 mm. In order to eliminate measurement errors from axial-strain and bending effects, the 81°-TFG was fixed on the plate with a small axial tension to maintain it straight.



(a) (b)

Figure 2 (a)The schematic diagram of the all-fiber transverse loading sensor based on a 45°-TFG and an 81°-TFG. (b) The 81°-TFG in an x–y coordinate system showing transverse load applied to its fast-axis.

The previously reported results [8] show that only fast-axis is sensitive to the loading effect, thus the transverse load was only applied to the equivalent fast-axis of 81°-TFG from 0 to 1.6 kg in a step of 0.1 kg by putting the weights on the top aluminum plat, as shown in Figure 2 (b). The transmission spectrum for each applied load is plotted in Figure 3. As clearly seen, when the load was applied to the 81°-TFG, the P1 mode peak was gradually decreasing but P2 peak oppositely increasing, due to the load induced polarization state change.

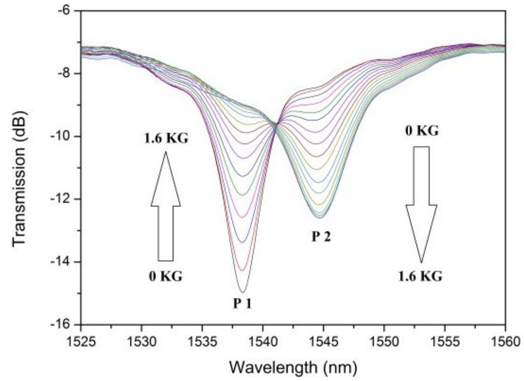


Figure 3 The transmission spectrum evolution of the 81°-TFG with transverse load from 0 kg to 1.6 kg applied to the fast-axis of 81°-TFG.

3.2 Implementation of transverse loading experiment using a single wavelength laser and a power meter

Based on the above experimental results, the directional polarization mode coupling behavior exhibited by the 45°-TFG and 81°-TFG may be explored for the implementation of an all-fiber loading sensor based on low cost power measurement. In real applications, it is desirable to use a low-cost and compact-size single wavelength source and power detector. To this end, we have replaced the BBS and OSA in Figure 2(a) with a tuneable laser (in a real application, this can be a cheap laser diode) and a power meter respectively.

The spectra of the paired polarization peaks (1538.32 nm and 1544.76 nm) of 81°-TFG under loading are shown in Figure 4 (a). In the experiment, we first tuned the laser to the P1 peak at 1538.32 nm and applied the load from 0 to 3.2 kg with an incremental of 0.1 kg to the 81°-TFG fast-axis and recorded the power reading accordingly, and then repeated this measurement by tuning the laser to match P2 at 1544.76nm. Figure 4 (b) plots the measured power values against the applied load for the two peaks. Clearly, the load can be measured up to the range of 10kg/m. Although the entire plots are not linear, there is an almost linear loading response range from 0 to 3.5 $kg \cdot m^{-1}$ at peak P1 and from 0 to 4.0 $kg \cdot m^{-1}$ at peak P2, in which we estimate that the loading sensitivity is approximately 30.142 μW/ (kg· m^{-1}) and 16.319 μW/ (kg· m−1) respectively. As the load is measured in electronic signal form, this may provide a mechanism that potentially the signal may be transmitted wirelessly for remote control and monitoring.

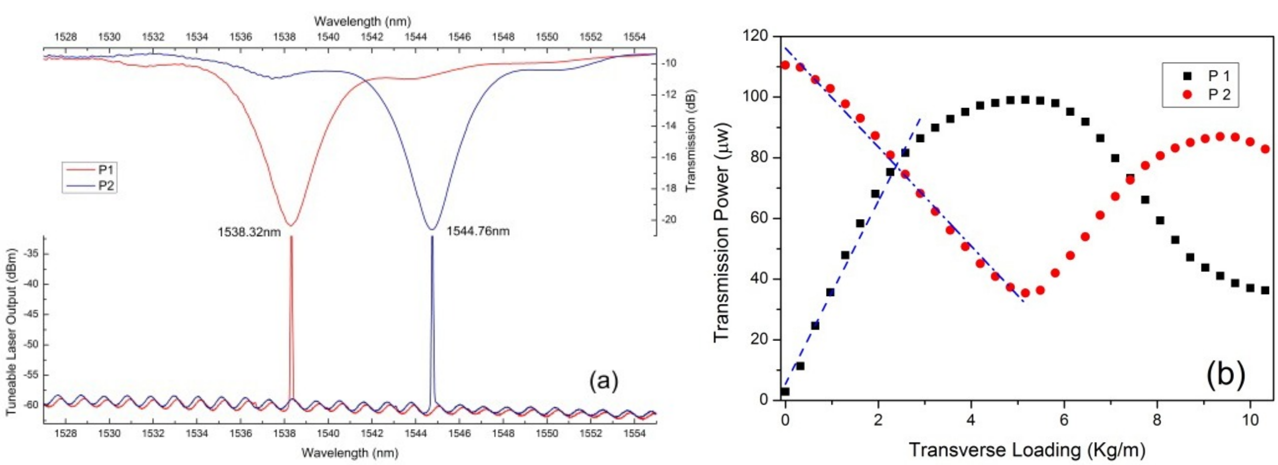


Figure 4(a) The upper plot is the transmission spectra of paired polarization peaks of 81°-TFG; the wavelength of the P1 loss peak is at

1538.32 nm and that of the P2 peak is at 1544.76 nm. The lower plot is the output spectra of the tunable laser set at the wavelengths of 1538.32 nm and 1544.76 nm, separately. (b) Transmission powers variation for the two orthogonal polarization peaks measured using the tunable laser and power meter.

4. Conclusion

In summary, we have demonstrated an all-fiber loading sensor based on a 45°- and an 81°-TFG. Such a sensor system removes the usage of the commercial polarizer and polarization controller, making the sensor system more simple and compact. More importantly, such a TFG based loading sensor can be demodulated using low-cost intensity measurement using single wavelength laser and photo detector, which is a unique and attractive advantage for real applications. Further work will be carried out on the measurement by applying the load to the slow-axis of the grating and the full analysis on load-induced polarization property of the 81°-TFG will be reported in future.

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