All-fibre twist sensor system based on 45° and 81° tilted fibre gratings

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ABSTRACT

We experimentally demonstrated a highly sensitive twist sensor system based on a 45° and an 81° tilted fibre grating (TFG). The 81°-TFG has a set of dual-peaks that are due to the birefringence induced by its extremely tilted structure. When the 81°-TFG subjected to twist, the coupling to the two peaks would interchange from each other, providing a mechanism to measure and monitor the twist. We have investigated the performance of the sensor system by three interrogation methods (spectral, power-measurement and voltage-measurement). The experimental results clearly show that the 81°-TFG and the 45°-TFG could be combined forming a full fibre twist sensor system capable of not just measuring the magnitude but also recognising the direction of the applied twist.

Key words: optical fibre, all fibre sensor system, tilted fibre grating, twist sensor.

1. INTRODUCTION

Fibre gratings have been widely exploited as optical fibre sensors for detecting and monitoring a range of physical parameters, such as pressure, strain, temperature, bending, refractive index, torsion or twist, etc[1-4]. Tilted fibre gratings (TFGs) are inherently capable of coupling light out of the fibre core. Unlike normal fibre gratings, the coupling of light by TFGs is highly polarisation dependent. The first TFG was demonstrated in 1990 by Meltz *et al*[5]. With advance of UV inscription technique and demands of their applications, the TFGs with large angle tilted structure have been studied and developed in recent years. In 2001, Li *et al.* stimulated and demonstrated the polarisation selectivity for 45°-TFG[6]. The High extinction ratio in-fibre polarisers based on 45°-TFG was firstly proposed and demonstrated by Zhou *et al.* in 2005[7]. Recently, detailed experimental investigation and theory analysis on ex-45° TFGs have been reported by Zhou *et al*[8], which revealed its forward-propagating cladding mode coupling function and temperature, strain and refractive index sensitivity characteristics. In addition, a twist sensor system based on ex-45° TFG has been reported by Chen *et al* in 2006[9].

In this paper, we report an all-fibre twist sensor system, which combines a 45°-TFG and an 81°-TFG. Here, the 45°-TFG polarises the input light and the 81°-TFG provide simple method to measure the twist based on its splitting polarisation modes. Moreover, we have investigated the relationship between the twist angle and the mode coupling strength and interrogated such an all-fibre twist sensor using low-cost light source and detector.

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. The strongest light coupling occurs at the wavelength determined by the phase match condition:

$$\lambda_{co-cl} = (n_{co} \pm n_{cl,m}).\frac{\Lambda}{\cos\theta}$$

Where n_{co} and $n_{cl,m}$ are the effective mode refractive indices of fundamental core and *m*th cladding mode, Λ is the grating period and θ is the tilt angle of the structure.

The 45°-TFG and the 81°-TFG were UV-inscribed in Corning SMF-28 fibre using scanning phase mask technique and a frequency-doubled CW Ar^+ laser. The SMF-28 fibre was hydrogen loaded at 150bar at 80°C for two days prior to the UV inscription to further enhance the photosensitivity. The 45°-TFG was UV-written in a 40cm-long fibre using a commercial phase-mask with 33.7° titled pitch pattern (made by Ibsen Ltd) with a period of 1800nm. The length of the 45°-TFG are is about 43mm. The figure 1a shows the polarisation extinction ration spectral response of the 45°-TFG measured by LUNA optical analysis system (measuring range from 1525nm to 1605 nm). As it can be seen that the polarisation extinction ration is more than 20dB between the 1525nm and 1565nm. The 12mm-long 81°-TFG was fabricated using a mask with a period of 6.6 μm purchased from Edmund Optics Ltd and the tilted structure was induced by rotating the phase mask at 79° in the UV-inscription system. The transmission spectrum of 81°-TFG shows it

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possesses a set of dual-peaks, corresponding to two sets of coupled modes with orthogonal polarisation states. Figure 1b shows the spectra of one pair of the dual-peaks when the grating was launched with two orthogonally and randomly polarised light. As shown clearly in the figure, when the grating launched with randomly polarised light, the two peaks are coupled with almost the same strength, thus showing 3-dB transmission loss, while when it launched with orthogonally polarised lights (P1 and P2), one peak is fully excited and the other almost diminished. It is this polarisation-related property providing a simple mechanism to measure twist/torsion.

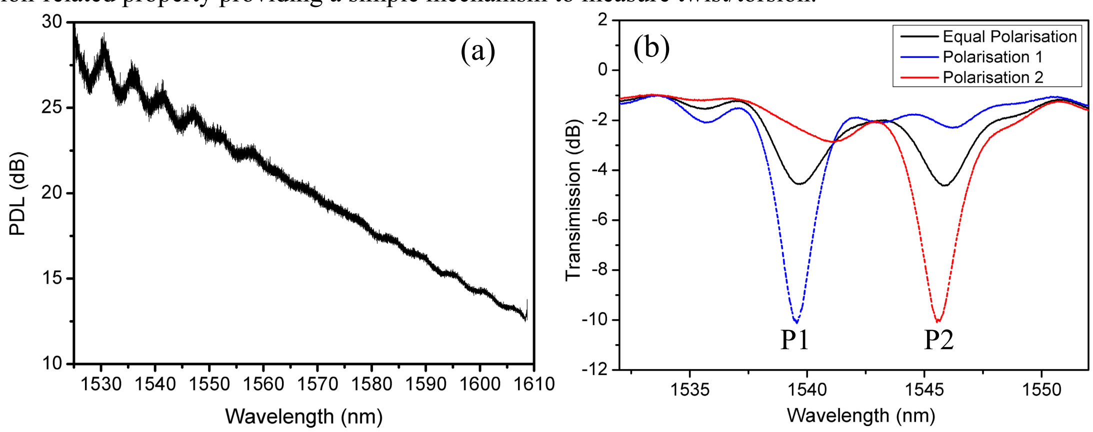

Fig. 1: (a) The polarisation extinction ration profile of the 45°-TFG; (b) the transmission spectra of 81°-TFG when launched with randomly and orthogonally polarised lights.

3. EXPERIMENTAL SETUP AND RESULTS

3.1 Experimental setup of spectrum interrogation method and results

The experimental setup of optical twist sensing system is illustrated in Figure 2. The light from a broadband source (BBS) was launched into the 45°-TFG to be polarised before entering the 81°-TFG. The 81°-TFG was fixed by a clamp on the incident light side and the other side of the fibre was housed by a fibre rotator and the output light was then monitored by an optical spectrum analyser (OSA) The fibre length between the clamp and rotator was 9.5cm. In order to eliminate measurement errors from axial-strain and bending effects, a small axial tension was applied to the fibre to maintain it straight.

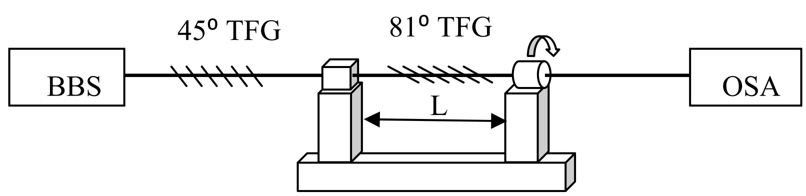

Fig. 2: The experimental setup of spectrum interrogation method for implementation of the proposed all-fibre twist sensor based on a 45°-TFG and an 81°-TFG.

Before the measurement was started, the twist position of zero degree was firstly calibrated by adjusting the rotator to set the pre-polarisation state at P1. Then, the twist was applied to the fibre in the clockwise direction from 0° to 180° with 10°-increments and the transmission spectrum for each applied twist was recorded and plotted in Fig. 3. As clearly seen, when the fibre containing 81°-TFG was twisted, the strength of P1 decreases but P2 increases. When the twisted angle reaches 180°, the P1 completely vanished and P2 reaches its maximum. We then repeated the measurement by applying the twist in an anti-clock direction and we saw a *vice versa* power exchange between P1 and P2.

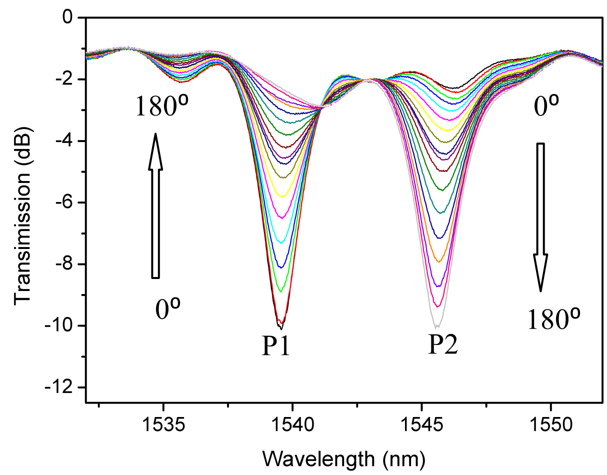

Fig. 3: Spectrum evolution of 81° TFG with twist angle from 0° to 180° in clockwise direction.

3.2 Experimental setup of power-detecting interrogation method and results

Based on above experimental results, the directional polarisation mode coupling behaviour exhibited by the 45°-TFG and 81°-TFG may be explored for implementation of an all-fibre twist sensor, as this system would not use bulky and expensive commercial polariser and polarisation controller. In practical applications, it is desirable to use low-cost and compact-size wavelength source and power detector. To this end, we replace the BBS and OSA with a single wavelength laser (SWL) and a power detector (although in the experiment, we used a tuneable laser). The schematic diagram of this system is shown in Fig. 4.

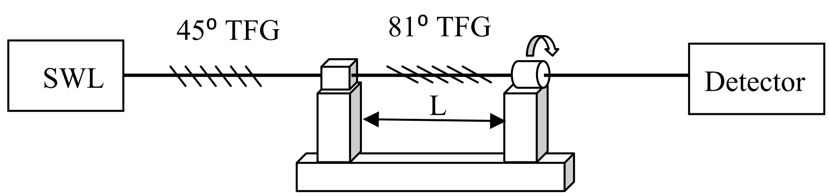

Fig. 4: The schematic diagram of the twist sensor system using a single wavelength laser and a power detector.

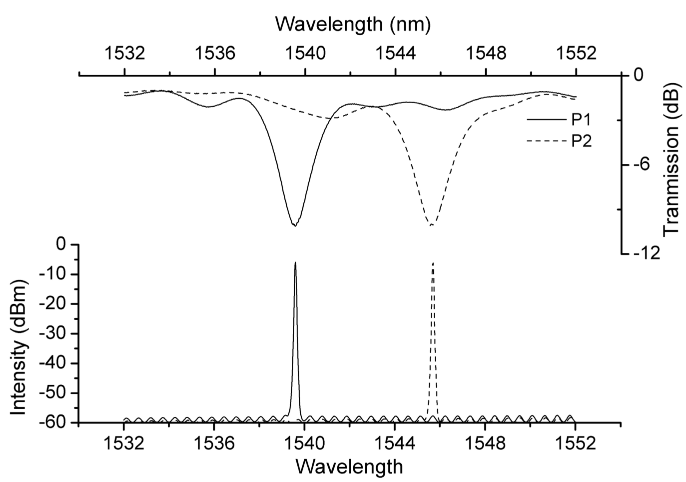

Fig. 5: The upper plot is the transmission spectra of the dual peaks of the 81°-TFG; the wavelength of P1 is at 1539.62nm and P2 is at 1545.74nm. The lower one is the output spectra of a tuneable laser set at the wavelength 1539.62nm and 1545.74nm.

Using the low cost power-detecting interrogation method, we carried out the twist measurement on the same 45°-TFG and 81°-TFG. The selected dual peaks of the 81°-TFG are at 1539.62nm and 1545.74nm (see in Fig. 5). We tuned the wavelength to the P1 peak at 1539.62nm and calibrated the zero position of sensor to set the pre-polarisation state at the minimum power by adjusting the rotator, then applied the twist from 0° to 180° with 10°-increments, and repeated this experiment by tuning the laser to P2 at 1545.74nm.

The Fig. 6a shows the result for the power measurement. The transmission power of P1 is increasing from -10 dB to -2 dB when the fibre was twisted from 0° to 180°, while, the transmission power of P2 is decreasing from -2 dB to -10 dB. From figure 6b, we see the similar results detected by changing the power meter to a photodetector showing the voltage is changing between 0mV and 3000mV for the twist changing from 0° to 180°. This may provide a mechanism that potentially the signal may be transmitted wirelessly for remote control and monitoring.

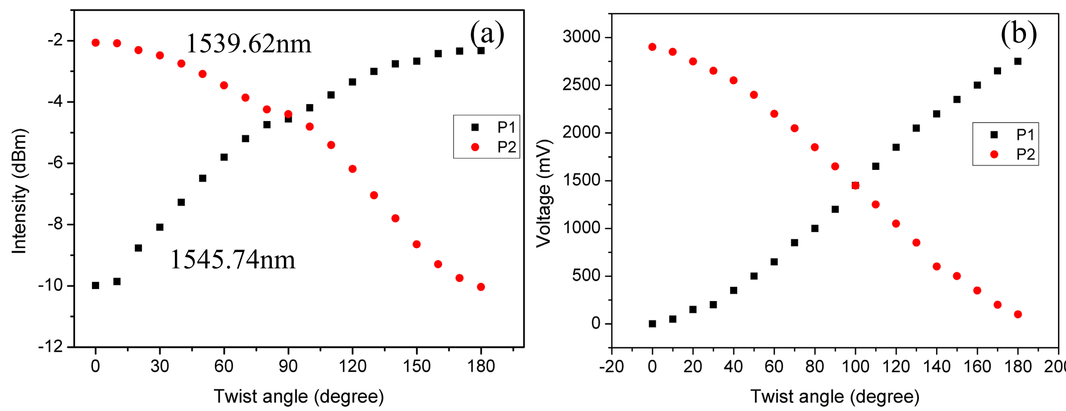

Fig. 6: Transmission powers for the two orthogonal polarisation modes measured by using low-cost power detaction methods: (a) using a power meter and (b) using a photodetector.

4. CONCLUSION

In summary, we have fabricated fibre grating devices with 45° and 81° tilted structures and experimentally observed a pronounced polarisation mode splitting effect. Finally, we demonstrated an all-fibre twist sensor system by using the combination of the 45°- and81°-TFG. The advantages of all-fibre and power measurement of this system provide many potentials for twist/torsion sensing applications using low-cost interrogation method and remote control and monitoring.

5. REFERENCES

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