Refractive Index Sensitivity Enhancement of 81° tilted Bragg Gratings by Cladding etching

Edward Davies[1], Pouneh Saffari, Chengbo Mou, Kaiming Zou and Lin Zhang.
Aston University

ABSTRACT

The properties of etched large angle tilted gratings (81°) are investigated. The attenuation peaks of the modes are found to shift to shorter wavelengths at a rate of ~5nm/min in a solution of 10% HF acid. The most sensitive modes are examined for different etching times creating the relationship that longer etching times results in an increase in overall sensitivity. Comparing the sensitivity of the tilted fibre grating, etched for 6 hours, 506.9nm/unri and the most sensitive LPG, period 164µm, 389.2nm/unri in the RI range 1.30-1.40 shows that the produced tilted grating is more sensitive than the LPG and in this range would ideally be suited for the used in Bio-sensing applications.

1 INTRODUCTION

The principle of Fibre Bragg (FBG) and Long period (LPG) Gratings has long been established as the coupling of light between the core mode to the counter and co-propagating cladding modes, respectively. The resonant wavelength that the coupling occurs to is affected by external stimuli which can cause a shift and change in attenuation; it is this property that has led to the fabrication of sensors for temperature, strain[1] and refractive index[2]. A sub-set of these two grating types is that of the Tilted Fibre Bragg Grating (TFBG), which is like that of the FBG except that the refractive index modulation is offset with respect to the core by an angle. Through the control of this angle the TFBG properties can be adjusted, with small tilted angels coupling to the counter propagating cladding modes and with larger angles coupling to the co-propagating cladding modes, , and are governed by the phase matching condition as,

$$\lambda_{res} = (n_{co}^{eff} - n_{cl}^{eff})\frac{\Lambda}{cos\theta} \tag{1}$$

where λ_{res} is the resonant wavelength, n_{co}^{eff} is the effective index of the core mode, n_{cl}^{eff} is the effective index of the cladding mode, is the period of the grating and θ is the angle of the grating. The effective index of the cladding mode is influenced by surrounding refractive index the resonant wavelength shifts, hence enabling the large angle TFBG to be used as a sensor [3]. In this way the TFBG is similar to a LPG, however, there are some distinctions. The TFBG now has a polarization dependence due to the non uniformity of the periodic index modulation, Fig. 1, which has previously been used as a polarizer [4]. This creates a slow and a fast axis within the core similar to that of a polarisation mainting fibre causing a dual peak response in the spectrum. They also exhibit a low thermal sensitivity making them suitable for accurate sensing compared to the high cross sensitivity of an LPG[3]. Finally the period used means that the light is coupled to the higher order modes meaning the effective index of the modes is about ~1.41 ri, smaller than the lower order modes, making the attenuation peaks disappear when the surrounding refractive index reaches this threshold, since no modes can exist. However combining this with the low cross thermal sensitivity can make them ideal for bio-sensing applications, in which the refractive index range is often below the threshold of the cladding modes effective index.

This work investigates the behaviour of the gratings due to decreasing the size of the cladding radius through etching. Although this has previously been done with small angled TFBG [5] to our knowledge it has not previously been reported for the large angled TFBG with the aim of the work to increase the refractive index sensitivity. It has previously been reported that the resonant wavelength will shift due to a reduction in the cladding radius [6], it is also known that different modes have different sensitivities [7]. By using these two properties we were able to shift the resonant wavelength of more sensitive modes into the spectrum of a broadband light source and evaluate the associated increase in sensitivity that arises

[1] daviesem@aston.ac.uk

20th International Conference on Optical Fibre Sensors, edited by Julian Jones, Brian Culshaw, Wolfgang Ecke, José Miguel López-Higuera, Reinhardt Willsch, Proc. of SPIE Vol. 7503, 75036X
 · doi: 10.1117/12.834906

2 EXPERIMENT

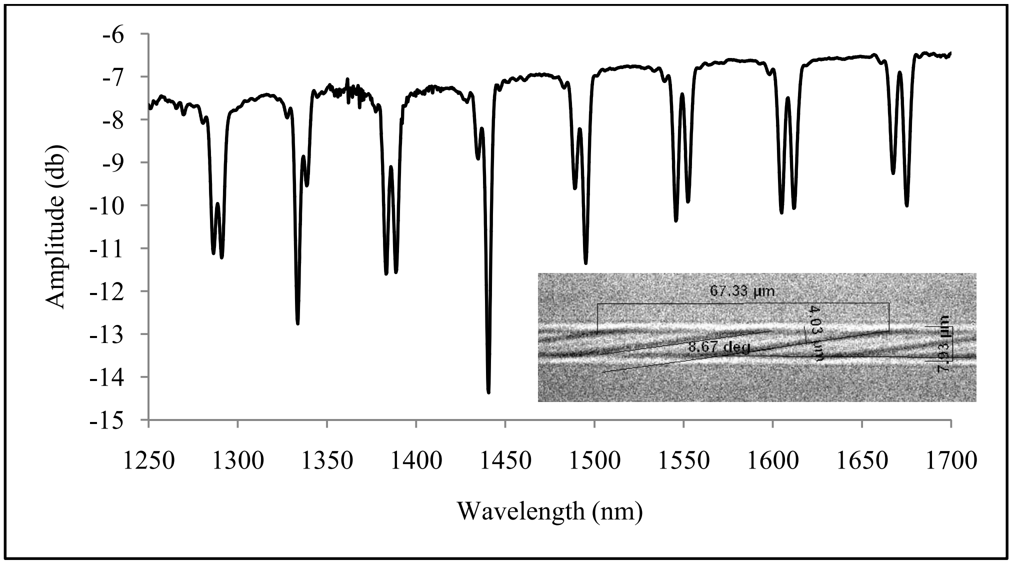

Figure 1 is the transmission spectrum of an 81□-TFG before etching, showing typical dual-peak feature due to polarisation mode split effect. Inset: microscopy image of the 81^{o}-TF

The large-angle TFGs were inscribed in H_2-loaded standard telecom fibre (SMF-28) using a 244nm UV beam from a frequency doubled Argon ion laser and the standard scanning mask technique. The amplitude mask (Edmund Optics) used for fabricating the large-angle TFGs having a period of 6.6μm was rotated by 79° in respect to the fibre axis in the UV-inscription to generate index fringes at 81° in the fibre core. The 81°-TFGs were characterised using a broadband source and an optical spectrum analyser and the typical transmission spectrum is shown in Figure 1**.** As clearly see from this figure that the 81°-TFG shows a typical dual-peak feature in transmission, causing by the polarisation mode splitting.

The etching experiment used HF acid of 10% concentration. Three 81°-TFGs were immerged into a container with HF acid solution in a safety fume cupboard. The spectral evolution of the one of the 81°-TFGs was monitored in-situ and the spectrum was recorded every 5min. The three TFGs were withdrawn from the HF solution in turn at the time intervals of 90min, 135min and 6hours. All etched gratings were thoroughly cleaned using the standard procedure before being implemented for any RI experiment.

For the RI response the TFBG were situated in a metal 'v' groove, the advantage to this are twofold; the groove keeps the fibre in position minimising peak shift due to bending or polarisation change while the metal being in contact with the optical bench acts as a heat sync keeping the temperature of the samples at a constant. The fibres were immersed in Cargille refractive index liquid, which are an industry standard certified to ±0.0002, ranging from 1.30 to 1.40 RI. After each immersion the TFBG were cleaned using ethanol followed by distilled water and then allowing to dry, the cleaning process was ratified by ensuring the spectrum returned the initial air reading.

3 RESULTS OF TFBG ETCHING AND RI SENSING

When the TFG is immerged in HF acid, we expect to see two phenomena: (i) the feature of dual resonance peaks disappears as the RI value of the acid is high enough to cause the paired peaks to merge; (ii) all resonance peaks will shift to shorter wavelength side as the fibre cladding becomes thinner. Fig. 2 (a) displays the spectral evolution of the in-situ monitored 81°-TFG immerged in 10% HF acid for 45 min. From the figure we can see clearly that all peaks are blue-shifting but with different speeds: the higher order modes shift faster than lower order modes. The plots for the blue-shifts for the 3 peaks at the longest wavelengths against etching time in Fig. 2 (b). From the plots in Fig. 2 (b), the etching induced shift rate is approximately -5nm/min and the mode at the longest wavelength shifts slightly faster than the shorter wavelength mode. Due to the rapid shift of the attenuation peaks, no credible data for comparison could be made for the modes with the same orders after 45min etching since they have shifted out of the broadband light source range. It is estimated that for HF acid of 10% concentration, 0.12μm of the cladding can be removed per minute, thus after 6 hours etching, the cladding diameter is reduced to ~80μm. This remaining cladding is still thick enough to maintain the robustness of the grating.

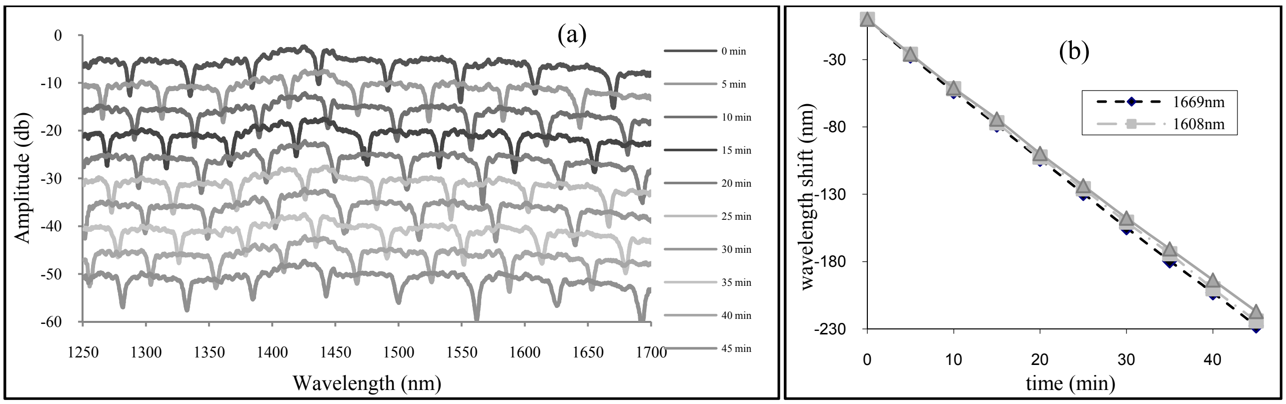

Figure 2 (a) 81°-TFG spectral evolution during the etching. (b) Wavelength shifts against etching time for the 3 longest wavelength peaks.

Three 81°-TFGs, which were etched for 90 min, 135 min and 6 hours, were investigated for RI sensitivity using a set of index oils with RIs from 1.30 to 1.40. The spectrum for each index gel measurement was captured on the optical spectrum analyser and the whole set of data were analysed for each TFG. Fig. 3 (a) plots comparatively the RI sensing results for three etched and one un-etched TFGs and it can be seen clearly that the RI sensitivity increases with decreasing cladding thickness and the TFG etched for 6 hours gives the highest RI sensitivity.

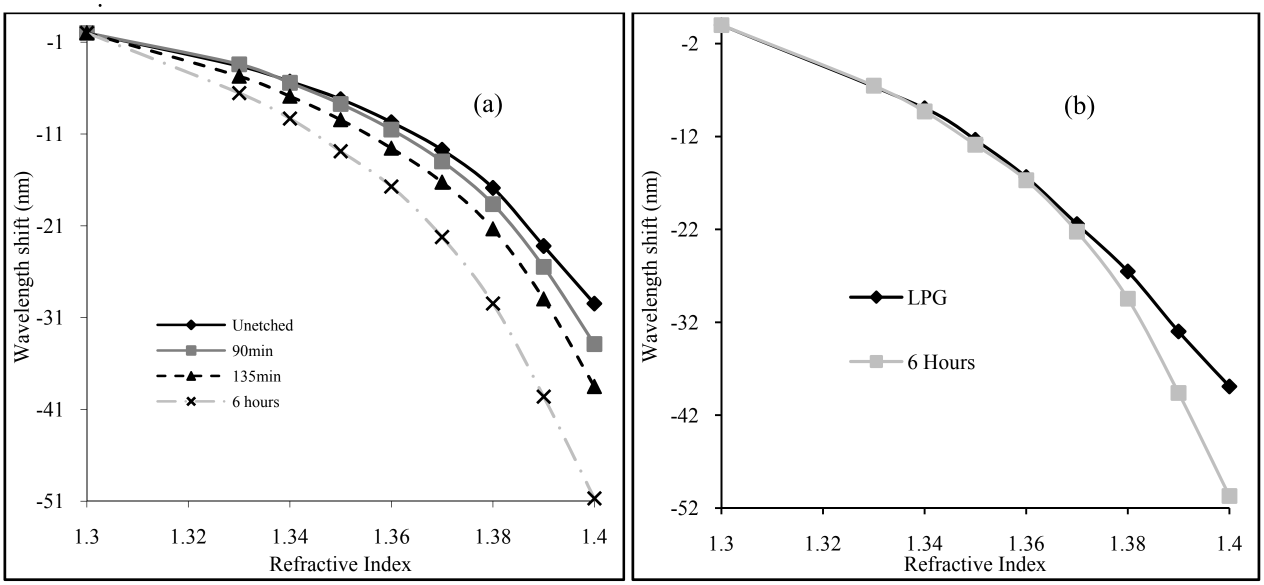

Figure 2 is the RI sensitivity of the different etching times TFBG (a) and (b) is a comparisson betwen the 6 hour etched TFBG and the most sensitive dual resonance LPG of period 164μm

To date, the majority in-fibre RI sensors are LPG structure based and the dual-peak LPGs have been reported to exhibit exceptionally high RI sensitivities. Fig. 3 (b) is plotted to compare the RI responses for our most sensitive TFG (etched for 6 hours) and an dual-peak LPG of 160μm period [8]. From the figure we can see that for the lower RI range from 1.30 to 1.36, both TFG and LPG exhibit a similar RI sensitivity, but for the range from 1.36 to 1.40, the etched TFG gives an average RI sensitivity of 506.9nm/URI while the dual-peak LPG's sensitivity is 389.2nm/URI. This evidently proves that by employing a relatively easy etching process, the TFGs could be shaped more sensitive to RI change and become desirable in-fibre sensors for chemical and biological sensing applications

4 CONCLUSION

Large angle TFBG's behavior due to etching and RI response were investigated. It was found that the cladding modes of a TFBG are affected by etching and hence cladding radius, to the extent that the attenuation peaks of the modes rapidly shift to shorter wavelengths. This re-ordering of the modes enables the examination of modes with higher sensitivity than that usually seen. Three 81°-TFGs were subjected to the etching using 10% concentration HF acid for 90 min, 135 min and 6 hours, respectively. The most etched TFG gives the highest RI sensitivity. More importantly, we have compared this TFG with a dual-peak LPG in the RI range from 1.36 to 1.4; the former exhibits an RI sensitivity of 506.9nm/URI which is significantly higher than the value of 389.2nm/URI compared to the latter. In addition, attention must be drawn to the fact that even after 6 hours etching, the remaining cladding is still about 80μm, which will not affect the robustness of the device. Further work will be carried out to implement these etched large-angle TFGs as bio-chemical sensors using bioactive coatings and we anticipate the further developed TFGs could become more desirable in-fibre sensor devices for future chemical and biological sensing applications.

5 ACKNOWLEDGEMENTS

Edward Davies would like to thank the ESPRC supporting his doctoral training grant.

6 REFERENCES

[1] Vikram Bhatia and Ashish M. Vengsarkar, "Optical fiber long-period grating sensors," *Optics Letters*, vol. 21, no. 9, pp. 692-694, May 1996.

[2] Alan D. Kersey and Frank Bucholtz Heather J. Patrick, "Analysis of the Response of Long Period Fiber Gratings to External Index of Refraction," *Journal of Ligthwave Technology*, vol. 16, no. 9, pp. 1606-1612, September 1998.

[3] Kaiming Zhou, Xianfeng Chen, Lin Zhang and Ian Bennion, "Optic sensors of high refractive-index responsivity and low thermal cross sensitivity that use fiber Bragg gratings of >80° tilted structures," *Optics Letters*, vol. 31, no. 9, pp. 1193-1195, May 2006.

[4] A. G. Simpson, X. Chen, L. Zhang, and I.Bennion K. Zhou, *Optics Letters*, vol. 30, p. 1285, 2005.

[5] K. Chah, F. Lhommé, M. Debliquy, D. Lahem, M. Blondel and P. Mégret C. Caucheteur1, "Enhancement of Cladding Modes Couplings in Tilted Bragg Gratings Owing to Cladding Etching," in *Fibres and Optical Passive Components, 2005. Proceedings of 2005 IEEE/LEOS Workshop on*, 2005, pp. 234- 239.

[6] Yunqi Liu, Mei Nar Ng and Xiaoyi Dong Kin Seng Chiang, "Analysis of etched long-period fibre grating and its response to external refractive index," *Electronic Letters*, vol. 36, no. 11, pp. 966-967, May 2000.

[7] L. Zhang and I. Bennion T. Allsop, "Detection of Organic aromatic Compounds in Paraffin by a Long-period fiber grating sensor with optimized sensitivity," *Optics Communications*, vol. 191, pp. 181-190, May 2001.

[8] L Zhang, X. Shu and I. Bennion, "Sensivity Characteristics of Long-period fiber gratings," *Journal of Lightwave Technology*, vol. 20, no. 2, pp. 255-266, February 2002.