Modeling and Production of High Birefringence FOBG Sensors

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ABSTRACT

Fibre Optic Bragg Grating Sensors are modelled and studied in high birefringence fibre. Coupled mode theory and multi layer approach are used to predict the spectral characteristics of the structure. Results are compared with experimental characterization of devices produced by UV light using the external method.

Keywords: Gratings, Fibre Optics, Sensors

1. INTRODUCTION

Fibre optic Bragg grating (FOBG) sensors are very attractive due to intrinsic characteristics of the Silica fibre and to the optically encoded signals given by the reflected light in the FOBG refractive index structure.[1] FOBG are extensively used to measure strain and temperature,[2] as those parameters shift the spectral band of the reflected light due to photo elastic and thermo optic effects. Strain measurements are of particular importance in several engineering applications like, aerospace, mechanical structures, composites, biomedical ... However, normal FOBG sensors are only sensitive to longitudinal strain, due to the glass characteristic of Silica fibre. Measurements of strain along several directions require the use of multi FOBG sensors, bulky and with several optical ports to be monitored. For some applications it would be desirable to have a single FOBG sensor able to measure strain along different axes.[3,4]

One alternative for anisotropic strain measurement is the use of FOBG written in HiBi fibre as, e.g., PANDA fibres (see fig. 1). Due to the intrinsic stress induced birefringence the x and y polarizations of the LP_{01} mode are now split and have each one a different effective index. This means that the Bragg wavelength of the FOBG is also different for each polarization and, with non polarized light launched into the fibre, a two peak spectrum should be observed. When an uniaxial transversal stress is applied to the fibre, the internal strain will induce different changes in the refractive index along and perpendicular to the strain axis. Such changes will cause each of the two peak structure to suffer a proper wavelength shift. A system of two equations can be used to obtain each strain component.

However, the two peak structure above mentioned is not always seen for a FOBG in HiBi fibre. Each of the spectral reflection bands has a FWFZ – *full width at first (side lobe) zero* – bandwidth, $2\Delta\lambda$, given by[5]

$$2\Delta\lambda = \frac{\lambda^2}{\pi n_{eff} L}\sqrt{(kL)^2 + \pi^2}$$

where λ is the central wavelength, n_{eff} is the effective refractive index, k is the coupling constant between the forward propagating mode and the back reflected one and L is the grating length. From eq. 1 it can be shown that, upon the grating parameters (k, L, n_{eff}) both spectra can overlap into a single, broadened reflection band. Usually this condition occurs when the kL product is high, the so called strong coupling situation. When the coupling is weak the two peak structure is seen. The described mechanism suffers also from the phase matching along the periodical refractive index that forms the grating. To have phase coherence leading to a narrow line width, the length of the structure should be large.

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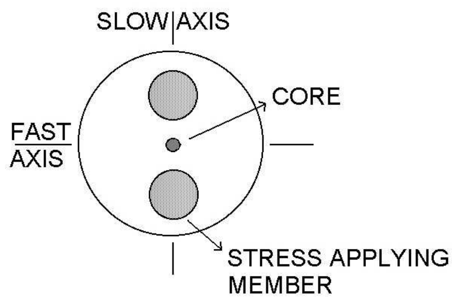

Figure 1. Schematic structure of HiBi Panda fibre.

2. NUMERICAL SIMULATION

The simulation of FOBG uses coupled mode theory to describe both the power in the launched mode (usually the fundamental mode of the fibre) and in the counter propagated one. The power coupling is described by the refractive index profile along the device. Transfer matrix methods are useful to describe the power coupling between different devices as, e.g., two successive gratings or gratings linked by phase shift regions.

We used an association of both methods to model FOBG in HiBi fibres. Each polarization was modelled by one grating and both are linked by a phase shift region. This method simplifies the problem as true polarized modes are not required in its description. This assumption is validated by the polarization preserving properties of the used fibre. The high birefringence in fact prevents coupling between both polarizations, so that their propagation can be treated as one isolated from the other.

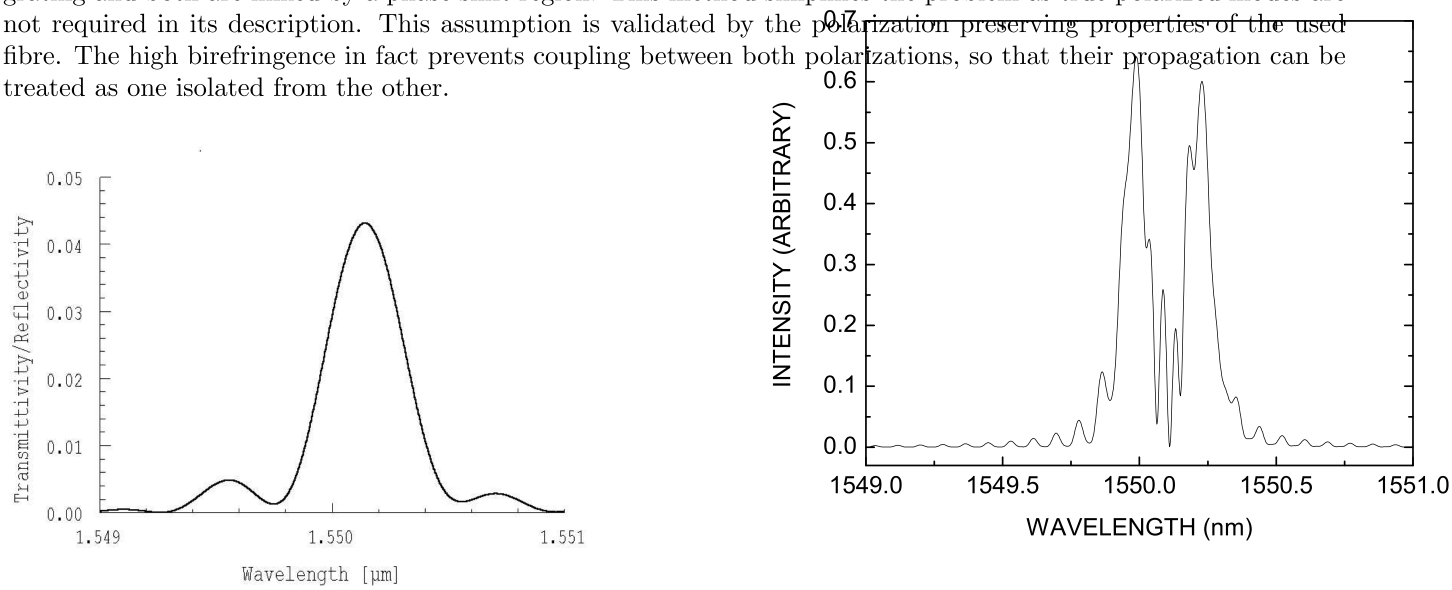

Figure 2. Numerically simulated spectra of FOBG in HiBi fibre. Left: unresolved (strong coupling), rigth: resolved (weak coupling).

Fig. 2 depicts simulated spectra from FOBG in HiBi PANDA fibre. The spectrum in the left side corresponds to a situation of strong coupling, where only a broadened band can be observed. In contrast, the use of weak coupling, shown on the right side of that figure, presents now the two peak structure associated with the Bragg reflection of each polarized mode. (The oscillatory aspects between both peaks are due to Fabry Perot modes generated by the two grating structure.) By changing the optical parameters of each polarization grating, it is possible to design the sensor in order to obtain the resolved structure. Again, apart from the low k, it is necessary to have a long grating length, L, to achieve a good spectral profile.

3. EXPERIMENTAL

FOBG were written in HiBi PANDA fibre using a phase mask interferometer illuminated by UV light (257 nm) from a frequency doubled Ar^+ ion laser. The fibre optic was previously keep in hydrogen atmosphere for a few days in order to enhance its photosensitivity, which permits a writing time is in the order of few minutes. Due to the reduced area of the beam the grating length is estimated to be ≈ 1 mm. Gratings were measured using an Optical Spectrum Analyser (OSA), after being illuminated with the light from a broadband LED through an optical coupler (see Fig. 3 for a schematic). The reflected light was isolated from spurious Fresnel reflection on the fibre ends by immersing such terminations in index matching liquid. Further details of the experimental apparatus are already published.[6] A stress applying apparatus (shown in Fig. 3) was used to apply uniaxial load into the FOBG. A glass plates is pressed due to the weight suspended at the tip of the hinged arm. The plate is also supported by two other fibres, to avoid tilt. The position of the FOBG, where the plate shall be positioned, is easily detected by proximity heating the fibre with a soldering iron tip while observing the optical spectrum in the OSA. The shift in the optical spectrum pinpoints accurately the FOBG site.

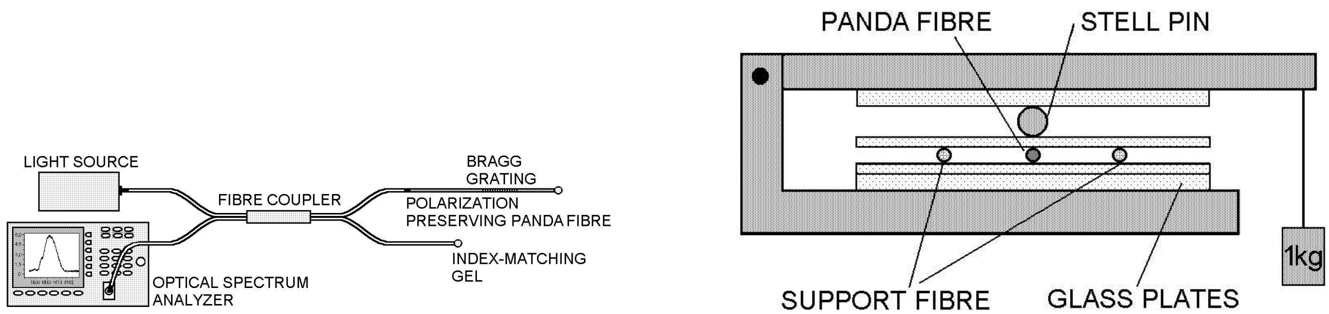

Figure 3. Experimental set up (left) and stress applying system (right) used to characterize FOBG in HiBi fibre.

The resulting grating spectrum, when no load is applied, contains a single broadened band with 1 nm bandwidth (FWHM), a further evidence of the strong coupling obtained. When the fibre is subjected to uniaxial stress the spectrum shows no changes up weights of 6 kgf. From that point on, the measured band starts to split, presenting a two peak pattern (even if not completely resolved), as shown by the successive traces on Fig. 4. For the maximum attainable load (12 kgf) the experimental measured peaks are 0.8 nm apart.

The last measured band (corresponding to 12 kgf) can be fitted by a superposition of two grating spectra[5] (see fig. 4 right), with the characteristic parameters given in table 1.

Table 1. Grating parameters obtained from best fit, A_i is the relative strength, see text for the other.

Grating	λ (nm)	$2\Delta\lambda$ (nm)	kL (m)	A_i
1	1511.21	1.63	0.8697	0.50
2	1512.13	1.63	0.8677	0.50

From the estimated length of the grating, $L\,(\approx 1\,\text{mm})$, we obtain approximate values for the coupling constants of each grating, $k \approx 869.74\,\text{m}^{-1}$.

4. CONCLUSION

It is possible to produce FOBG in HiBi fibres that might be used to simutaneously measure strain along two principal directions. The numerical simulation of such structure points, as expected, to long gratings, $L > 10$ mm, in order to separate the spectra from each polarized mode and to have narrow reflection bands (this feature helps to obtain better experimental resolution during strain monitoring and measurement). The numerical simulation can

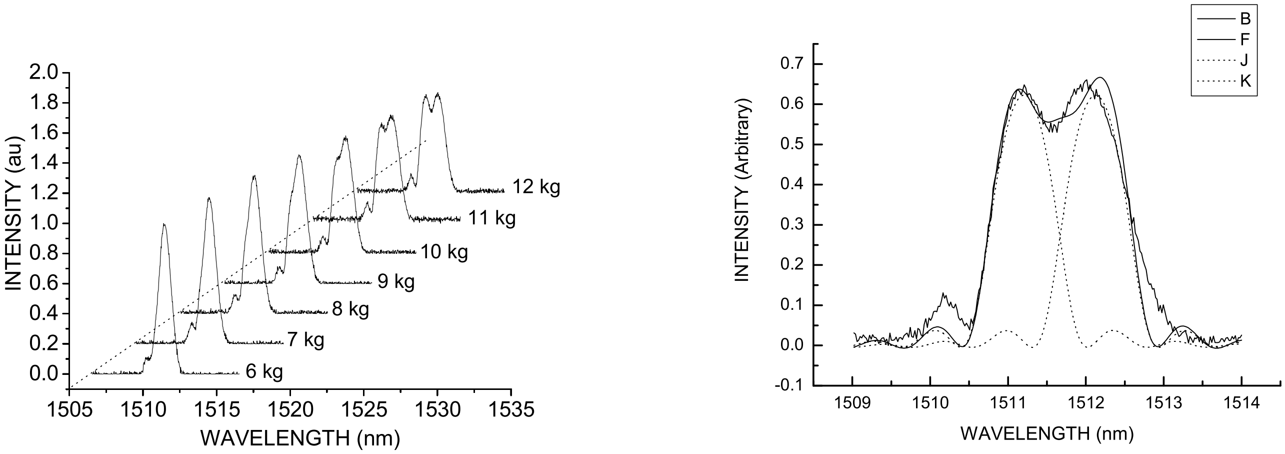

Figure 4. Spectra of FOBG written in HiBi (Panda) fibre, under several applied loads, from 6 kgf to 12 kgf (left). Detail of last spectrum (12 kgf load), with theoretical fitted bands: dotted lines - individual bands, solid line - superposition (right).

be improved to include other features (e.g., apodization, longitudinal index profile, . . .) that might also enhance the spectral characteristics of the FOBG aimed to sense strain along different axes.

The production of adequate FOBG in HiBi fibres is possible using standard phase mask interferometer techniques, but it is recommended to have a beam expansion in order to obtain long gratings. For common HiBi fibres, the obtainable intrinsic birefringence requires grating lengths at least in the order of 10 mm. For well separated, narrow gratings, lengths up to 5 times that amount may be required. Another possibility to produce long gratings is to write successive FOBG sections by moving the fibre, although care shall be taken both to the positioning control and to stitching errors.

ACKNOWLEDGMENTS

This work was supported by CTPETRO/CNPq, CNPq, CAPES, FAPESP, CAPES/ICCTI project 58/00 and Fundação Araucária. Dr. Kalinowski thanks *Universidade de Aveiro* and *Instituto de Telecomunicações – Polo de Aveiro* for their support during a sabbatical leave.

REFERENCES

1. K. O. Hill and G. Meltz, "Fiber Bragg Gratings Technology and Overview". *J. Lightwave Technol.* **15**, pp. 1263-1276, 1997.
2. R. C. Chaves, I. Abe, M. J. D. dos Santos, M. J. Pontes, H. J. Kalinowski, C. A. de Francisco and M. A. Romero, "Strain and Temperature Measurements in Power Systems with Multiplexed Fiber Optics Bragg Gratings Sensors". *Journal of Microwave and Optoelectronics* **2(1)**, pp. 54–63, 2000.
3. E. Udd, W. L. Schultz and J. Seim, "Multi-axis fiber grating strain sensor appplications for structural monitoring and process control". *Proc. SPIE* **3538**, pp. 206–214, 1999.
4. C. M. Lawrence, D. V. Nelson and E. Udd, "Measurements of transverse strain with fiber Bragg gratings". *Proc. SPIE* **3042**, pp. 218–228, 1997.
5. T. Erdogan; "Fiber Grating Spectra". *J. Lightwave Technol.* **15(8)**, 1277-1294 (1997).
6. I. Abe, J. L. Fabris, B. W. Diesel, M. C. Fugihara, H. J. Kalinowski and C. L. Barbosa, "Bragg gratings written in high birefringence optical fiber for transversal strain sensors ". *Proc. XXVIII ENFMC in: Annals of the Brazilian Commission for Optics* , 2001.