Greater Than 90nm Continuously Wavelength-tunable Fibre Bragg Gratings

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Abstract: We report silica-based fibre Bragg grating filters with wavelength tuning-spans well over 90nm using a simple set-and-forget beam bending tuning-package. The key operational parameters of the filters are maintained over the entire tuning-window.

1. Introduction

The evolution of transmission-systems from static point-to point links to dynamically re-configurable networks calls for the development of wavelength tunable optical devices. Ideally they should exhibit rapid and accurate tuning performances that require power only when tuned and no-power consumption when not tuning, i.e. a set-and-forget configuration. Furthermore, with the expansion of transmission-band-operation from C-band to L- and S-bands: filters with a large wavelength tuning range become necessary both from an inventory and a cost perspective. In addition, the capability of the filters to tune into the dead bands between the S-, C- and L- bands while they are not in service, becomes necessary to prevent cross-talk in WDM systems with tight channels separation.

On a number of occasions it has been demonstrated how fibre Bragg gratings (FBGs) have developed into some of the most suitable devices for selecting DWDM signals with channel spacing as low as 25GHz [1], owing to the almost arbitrary design possibilities of both their spectral and phase performances. The center wavelength of an FBG can typically be tuned/controlled by mechanical strain or temperature, with strain-tuning being the prefer method to achieve a wider tuning-range. However, recent demonstrations of wideband tuning of FBGs' have adopted axial compressive-stress, due to the fact that silica fibre is ~23 times stronger in a compressive-stress mode than in a tensile-stress mode [2,3].

In this paper, we demonstrate the widest ever reported tuning-range in any FBG configuration of 0nearly 100nm using a beam-bending method [4]. Furthermore, this tuning-range is achieved using a simple tuning package that allows for operation in a set-and-forget configuration. Additionally we show that the polarization-mode dispersion (PMD) and polarization-dependent loss (PDL) of the device remain low even under the extreme compressive and tensile stresses. All the key operational parameters of the filter are preserved throughout the entire tuning-window, showing the applicability of this device for simple, robust wideband tuning in next generation high data-rate WDM systems.

2. 2. Device configuration and principle of operation

Figure 1 shows the principle of our tunable package. A straight elastic beam of length L, held between two solid blocks, will be bent to form an arc-shape by horizontally translating the movable block inwards. The horizontal translation, Δz, of the movable block is related to the arc formed by the beam through

$\Delta z = L.[1-\mathrm{sinc}(\theta/2)]$, (1)

where θ is the central angle of the generated arc.

The bent elastic beam will experience compression/extension on its upper surface whilst its lower surface is stretched/compressed. The strain ε on the surfaces of the beam is related to the arc by

$\varepsilon = \pm\, d.\theta/L,\ L \neq 0$, (2)

where *d* is the distance from the neutral axis to the upper/lower (- +) surface of the bent beam. From (2) it can be seen that an increase in *d* can enhance the magnitude of compressive strain for a particular arc-curvature. In this work this is achieved by adhering a flexible slab onto the elastic beam. When a FBG is embedded into the flexible slab at a distance *d* from the neutral axis, its wavelength detuning, $\Delta\lambda$, will follow:

$\Delta\lambda = (1-\rho_e).\varepsilon.\lambda_B$, (3)

where λ_B is the Bragg wavelength of the FBG in idle condition and $\rho_e \approx 0.22$ is the photo-elastic coefficient of optical fibre.

In accordance to (1) and (3), Δz and $\Delta\lambda$ are correlated through the arc-angle, namely θ. Therefore, the amount of wavelength shift of the grating can be precisely determined by reading the horizontal translation from a micrometer-screw, which also serves as a driver of the package. The package renders no power consumption once a desired wavelength shift has been obtained.

Two FBGs were fabricated in a Deuterium loaded B/Ge/Si fibre using our "continuous grating writing technique" [1]. They were 3mm and 2mm long with center wavelengths of 1614nm and 1562nm respectively, were Blackman apodised to reduce the side-lobes and had a 3dB reflection-bandwidth of ~0.93nm. They were separately embedded into a flexible slab, which subsequently were adhered onto an *L*=100mm long elastic beam. This method constitutes composite bending substrates, which is used to enhance the *d* factor [5]. The effective *d*, which here is the distance from the neutral axis of each of the composite substrates to the grating axis, was 6mm and 4.6mm, respectively. The bending substrate with the embedded FBG was then inserted between the holding grooves of the above described tuning package to constitute tunable FBG filters.

3. 3. Experimental results and discussion

Fig. 2 shows the reflection spectra of the first tunable filter at various tuned locations, which are measured using a semiconductor optical amplifier (SOA) as broadband ASE source and an optical spectrum analyzer (OSA). The center wavelength of the FBG is continuously tuned from 1614nm to 1544nm when operated in compression-mode, and from 1614nm to 1634nm when operated

in extension mode, i.e. a total of 90nm. It stretches into the L+ band covers the entire L-band, crosses over the dead-bands, and reaches halfway into the C-band. The 3dB bandwidth variations of the grating filter are shown as black circles in Fig. 2. During the entire tuning-operation, the 3dB bandwidth variation remains <0.04nm, except for the most extreme case at 1544.3nm, where a 0.08nm variation in bandwidth is observed. We believe that this may be due to the onset of a slight buckle in the flexible slab. The wide wavelength tuning-range of -70nm implies that 5.6% of compressive strain has been imparted on the FBG. This value is well below the theoretical maximum tolerable strength of silica fibre in compression mode. The grating is also operated in extension-mode (+20nm) to demonstrate the overall flexibility of the package. The additional noise in the reflection-spectrum is not due to any imperfections generated by the tuning action to the grating but due to a limited amount of ASE-power from the SOA and limited sensitivity of the OSA.
Fig. 3 shows the theoretical relation between the wavelength shift and the normalized translation, $\Delta z/L$ of this tunable FBG device for various values of d. The rectangles are wavelength-shifts of the device measured experimentally as a function of $\Delta z/L$. The experimental results are in good agreement with the theoretical curve for $d = 6$mm. A small translation can induce a large wavelength shift when a large d is chosen, as illustrated by the theoretical curves with various values of d. In this experiment, the 70nm wavelength compression-shift is achieved with a 3.5mm displacement, and the 20nm extension-shift with a mere 400μm displacement. To clarify the situation that bending may induce birefringence and increase the PMD of the tunable FBG filter, we measured the PMD of the filter at various bent positions with a HP 8509B Lightwave Polarization Analyzer. Fig. 4 shows that the PMD < 1.6ps for all bend positions for this device. In addition, the PDL of the device has also been characterized, and no appreciable increment in PDL is observed. All values are well between 0.11 ± 0.03 dB (Fig. 4).
For the second tunable FBG filter, the tuned reflection spectra are demonstrated in Fig. 5. It has an improved 100mm long hybrid material bending substrate. This grating is 2mm long and is embedded at an effective d of 4.6mm. The grating has a center wavelength of 1562nm and it is continuously compressive-tuned to 1463nm, covering 99nm (8.13% of compressive strain). Again the additional noise in the reflection spectra observed when tuned toward the shorter wavelength regime is due to roll-off of ASE-power from the SOA. Its 3-dB bandwidth is observed to have negligible changes over most of the tuning range except the most extreme locations. This is possibly due to the limitation of the bending substrate at these points.

4. 4. Conclusion

We have demonstrated tunable FBG filters with a record wavelength tuning range of nearly 100nm using a simple bend-tuning technique. The performance of the devices is maintained over the entire operating regime. The wide-band and set-and-forget capabilities offers great advantages in future dynamic WDM networks.

5. References

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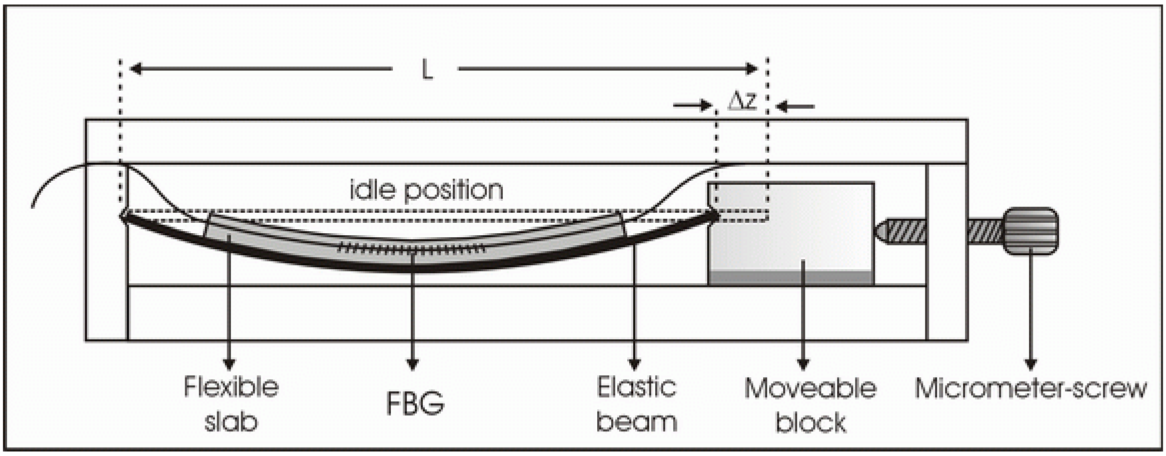

Fig. 1. Set-and-forget package configuration.

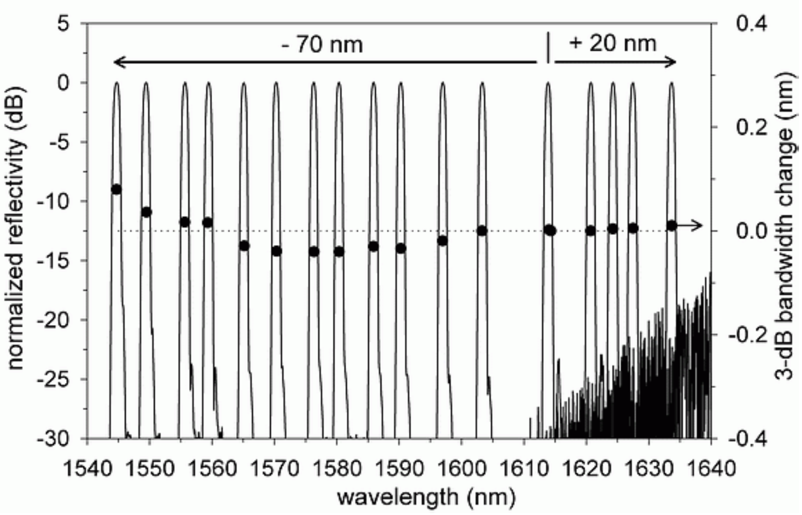

Fig. 2. 90nm total wavelength tuning range and 3-dB bandwidth-change in the tunable Bragg grating filter.

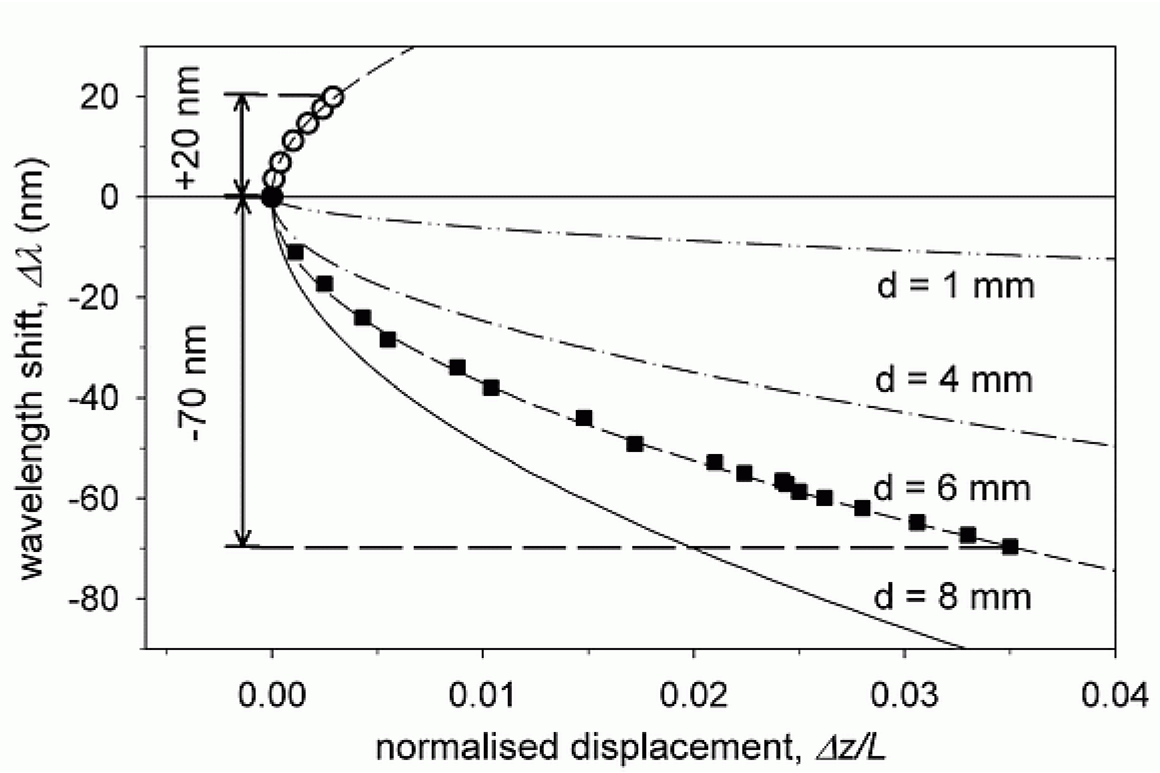

Fig. 3. Wavelength-shift against normalised horizontal displacement for different d (symbols: measured, lines: theory).

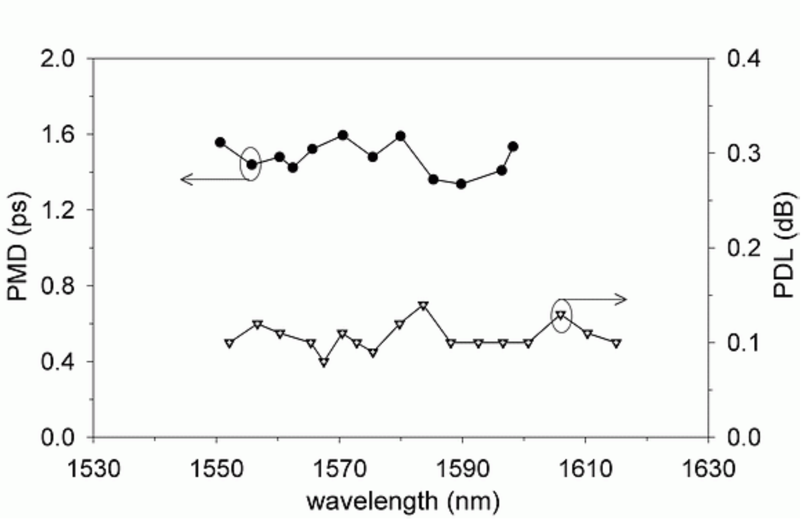

Fig. 4. PMD and PDL of the device at various tuned wavelength.

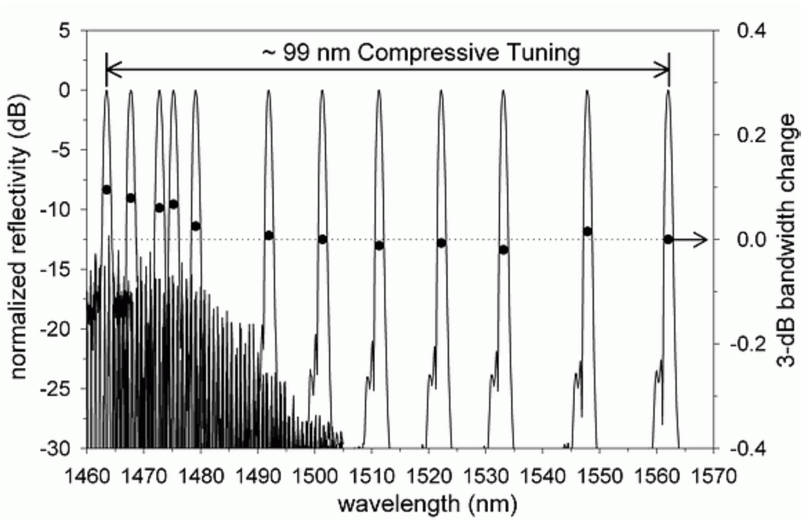

Fig. 5. Spectral coverage of over 99nm in compressive-bending mode.