Over 70 nm Wideband Tuning of Fiber Bragg Gratings Using a Compressive Bending Technique

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Abstract
We demonstrate, for the first time, a silica-based fiber Bragg grating (FBG) with a wavelength tuning range over 70 nm, using compressive bending given by a simple tuning package. The wide tuning range of the device (from 1614 nm to 1544 nm), covers the entire L-band and a half of the C-band. Its polarization-mode dispersion (PMD) and polarization-dependent loss (PDL) remain low over the full operating regime.

Introduction

The expansion of DWDM systems from the conventional band (C-band) to the short band (S-band) and the long band (L-band) calls for the development of various wavelength tunable optical devices. In the near-future dynamic reconfigurable networks, which will encompass operation bandwidth over 150 nm, it requires wavelength-selective filters with a large tuning range. In addition, the capability of the filters to tune into the dead band between the C and L bands, which is not in service, is necessary to prevent crosstalk in DWDM systems with tight channels separation.

The fiber Bragg gratings (FBG) is the most suitable for selecting DWDM signals with channel spacing ≤50 GHz owing to its narrow bandwidth and steep spectral edge. Its center wavelength can typically be shifted either by the strain or thermal effect. However, strain tuning is more preferable to achieve a wider tuning range. Recent demonstrations of widely tunable FBG are carried by using a compressive strain. This is because the silica fiber is 23 times stronger in a compression-strain mode than in a tensile-strain mode [1,2].

In this paper, we demonstrate a 70-nm wavelength tuning range of an FBG using compressive bending [3] given by a simple tuning package. To the best of our knowledge, this is the widest tuning range ever achieved with a silica-based FBG. We also find that the polarization-mode dispersion (PMD) and polarization-dependent loss (PDL) of the device are low enough under various compressive strains, showing applicability of the device to DWDM networks.

Principle of Operation and Fabrication of the Device

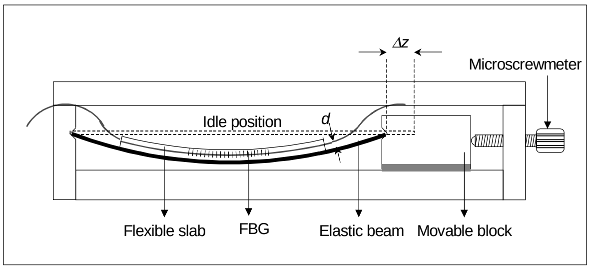

Fig. 1: Tuning Package for an FBG.

Figure 1 shows the tuning package for an FBG. A straight elastic beam with a length L, which is held within two blocks, will be bent downward to form an arc shape by horizontally translating the movable block inward. The horizontal translation, Δz of the movable block is related to the amount of arc formed by the beam as

$$\Delta z = L \cdot \left[1 - sinc(\theta/2)\right] , \tag{1}$$

where θ is the central angle pertain to the arc.

Meanwhile, the bent beam will experience compression on its upper surface whilst its lower surface is stretched. The compressive strain on the upper surface can be represented by

$$\varepsilon = -\frac{d \cdot \theta}{L}, L \neq 0 , \tag{2}$$

where d is the distance from the neutral axis to the upper surface of the bent beam. Increase in d can enhance the magnitude of compressive strain at a particular arc. This is achieved by adhering a flexible slab onto the elastic beam.

When an FBG is embedded in the flexible slab, its wavelength detuning will be dictated as follow:

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

where λ_B is the Bragg wavelength of the FBG in unstrained condition and $\rho_e \cong 0.22$ is the photoelastic coefficient of optical fiber.

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

The FBG used in the experiment was fabricated on a Deuterium loaded photosensitive fiber by moving the fiber relative to a phase mask which was illuminated with a UV laser [4]. Appropriate apodization was chosen to suppress spectral side lobes. The FBG was 3-mm long with a centre wavelength at 1614.3 nm and has a 3-dB bandwidth of 0.93 nm. It was then embedded into a flexible slab, which was adhered onto a 100 mm-long elastic beam. The effective *d*, which was the distance from the neutral axis of the composite beam to the grating axis, was 5.95 mm. The bending substrate with the embedded FBG was inserted between the holding grooves of the above-mentioned tuning package to constitute a tunable FBG filter.

Tuning Characteristics of the Device

Figure 2 is the 70-nm spectral coverage of the tunable device in reflection at various tuned locations. The center wavelength of the FBG is continuously tuned from 1614.3 nm to 1544.3 nm. It covers the entire L-band, crosses over the dead band, and reaches halfway the C-band. Corresponding 3-dB bandwidth variations are displayed as black triangles in Fig. 2. During the tuning, changes in the 3-dB bandwidth remain <0.04 nm, except for the most extreme tune at 1544.3 nm, where a 0.08-nm bandwidth change is observed. This may be due to the onset of a slight buckle in the flexible slab. The wide wavelength tuning range of 70 nm implies a 5.56% of compression imparted on the FBG. This value is well below the maximum tolerable strength of the silica fiber in a compression mode; therefore, it is possible to compress further down in wavelength to cover the whole C-band.

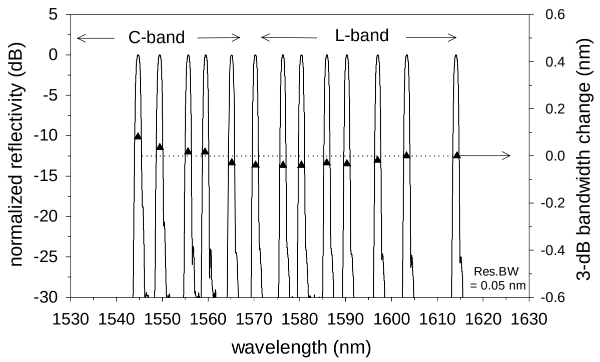

Fig. 2: 70-nm tuning range and 3-dB bandwidth change of the tunable device.

Figure 3 shows the relation between the wavelength shift and the normalized translation, $\Delta z/L$ of the tunable FBG device for various values of *d*. The rectangles are wavelength shifts of the device measured as a function of $\Delta z/L$. These are in good agreement with the theoretical curve for d = 6 mm. 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 70-nm wavelength shift is achieved with 3.5-mm displacement.

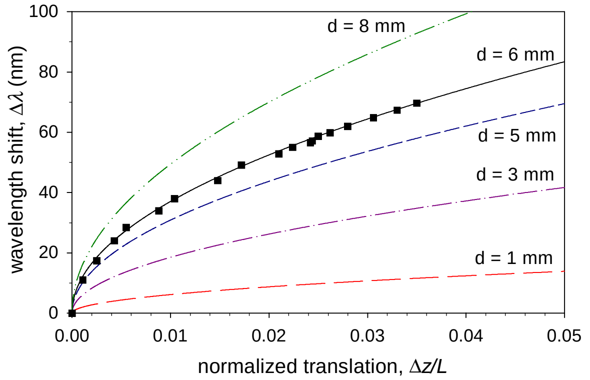

Fig. 3: Wavelength shift against the normalized horizontal translation of the tunable device.

In order to clear the doubt that bending may induce birefringence and increase PMD on the tunable device, we measured the PMD of the tunable FBG filter at various bent positions. Measurements were carried out by using a HP 8509B Lightwave Polarization Analyzer. Figure 4 shows that PMD < 1.6 ps for all bend positions. In addition, PDL of the device has also been characterized, and any appreciable increment in PDL is not observed. All values are well between (0.11 ± 0.03) dB.

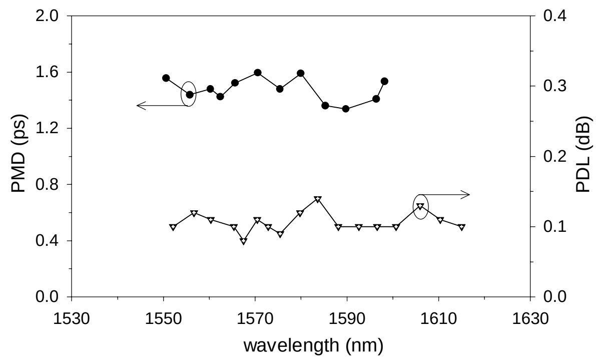

Fig. 4: PMD and PDL of the tunable device at various tuned positions.

Conclusion

We have demonstrated a tunable FBG, which has over 70-nm transmission band coverage, using a simple compressive-bending technique. The performance of the tunable device is maintained over the entire operation regime. Its wide band coverage offers advantageous applications in dynamic DWDM networks, which require broadband tunable filters.

References

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