JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 8, No. 3, June 2006, p. 1250 - 1253

A wide tunable range fiber Bragg grating filter

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A simple, low cost setup is designed for tuning the Bragg wavelength of a fiber Bragg grating filter. A linear Bragg wavelength tuning range of 20.5 nm is achieved, and the 3 dB bandwidth of the fiber Bragg grating spectrum shows little variations over the whole tuning region.

(Received October 6, 2005; accepted May 18, 2006)

Keywords: Fiber Bragg grating, Tunable filter, Mechanical strain

1. Introduction

With the increasing use of dense wavelength division multiplexing (DWDM) in today's telecommunication industry, fiber Bragg gratings (FBG) are widely used in various telecommunication and sensing applications due to the tunable properties of Bragg wavelength and bandwidth [1]. The property of tunable Bragg wavelength as well as flat top spectral response, narrow line-width and low insertion loss make FBG attractive for filtering and routing of different closely spaced wavelengths of light.

The Bragg wavelength of an FBG can be tuned by changing the temperature [2] or by applying mechanical strain on it [3-5]. Changing the temperature of the FBG results in a slow wavelength shift; hence, a small tuning range is achieved. Mechanical tuning of the FBG results in a faster and large response in terms of wavelength shift.

Recently, several mechanical tuning setups have been reported. One of the methods was that a FBG was mounted on a flexible beam where the beam was applied by an axial compressive strain [3]. The tuning range of 110 nm was achieved, but the Bragg wavelength shift was not directly proportional to the applied force. FBG embedded in a triangular beam of carbon-fiber material [4] showed a tuning range of 2 nm and repeatability of less than 0.4%. Based on the principle of a trapezoidal beam of uniform strength, a tuning range of 12.52 nm was achieved [5]. It had been demonstrated by using piezoelectric actuators, along with the beam bending method, that large wavelength shifts up to 45 nm can be achieved [6]. However, such devices were usually bulky and costly, due to the need for two piezoelectric actuators and high voltage amplifiers (1000 V, 100 W).

In this paper, a simple rectangular beam structure for tuning the Bragg wavelength is proposed. The principle of design and simulation results is described in Section 2. Experimental results and discussions are presented in Section 3. A conclusion is given in Section 4.

2. Principle of design and simulation results

The proposed design for tuning Bragg wavelength of FBG filter is shown in Fig. 1. A rectangular beam of an organic glass material is simply supported at the two ends. A micrometer is placed at the center of the top side of the beam. The loads are applied onto the beam by translation of a movable block, which is driven by the micrometer screw. A force diagram of the beam is shown in Fig. 2. The bending of the beam is obtained by applying two equal, vertical concentrated forces at the two points C and E. A FBG is epoxy-bonded onto the top surface of the beam between the two applied forces. The distances of these two forces from each end are both equal to *d* respectively. This bending under the loads will produce compression strain on the FBG; on the other hand, the loads can also produce tension strain if the FBG is placed on the bottom surface of the beam. The thickness, width and length of the beam are denoted as *h*, *w* and *L*, respectively.

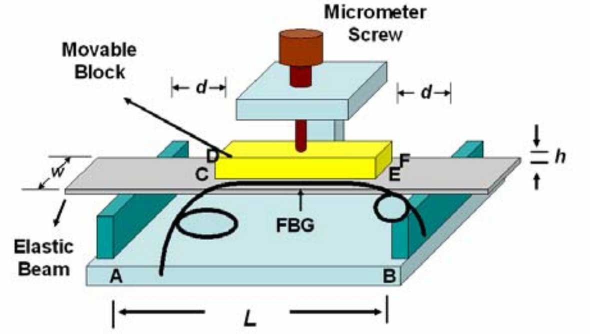


Fig. 1. Schematic diagram of the tunable fiber Bragg grating filter setup.

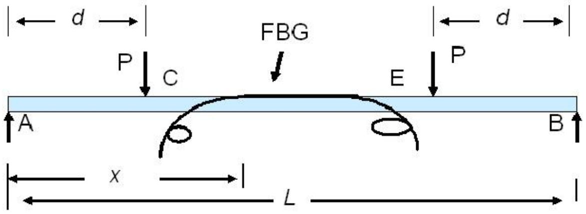


Fig. 2. Force diagram of the beam.

The bending moment at any cross section between the two forces ($d<x<L-d$) is

$$M(x) = Pd \tag{1}$$

Thus, the curvature of the neutral layer of the beam at any point x ($d<x<L-d$), can be given by [7]

$$\frac{1}{R} = \frac{M(x)}{EI_z(x)} = \frac{12Pd}{Ewh^3} \tag{2}$$

where $M(x)$ and $I_z(x)$ are the respective bending moment and the moment of inertia of the beam's cross section at x. E is the Young's modulus of the organic glass material. It can be seen from Eq. (2) that the curvature is independent of x, so that it is uniform along the beam between the two applied forces.

The deflections of the two points C and E on the beam are the same with the vertical displacement of the micrometer and can be given by [7]

$$\Delta z = \frac{Pd}{6EI_z}(3Ld - 4d^2) \tag{3}$$

By combining Eq. (2) and (3), this results in

$$\frac{1}{R} = \frac{6}{3Ld - 4d^2} \cdot \Delta z \tag{4}$$

The strain at the top layer of the beam on the FBG is thus given by

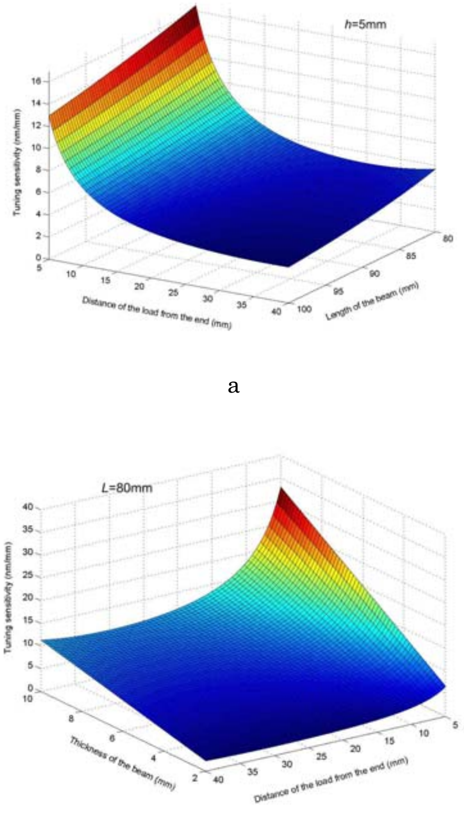
$$\varepsilon = \frac{1}{R} \cdot \frac{h}{2} = \frac{3h}{3Ld - 4d^2} \cdot \Delta z \tag{5}$$

When the beam is bent, the shift in the Bragg wavelength, $\Delta\lambda$, for any segment of the grating is directly proportional to the strain. Therefore, the final description of the shift in the Bragg wavelength with respect to the displacement Δz can be described as follows:

$$\frac{\Delta\lambda_B}{\lambda_B} = (1 - p_e)\varepsilon = (1 - p_e) \cdot \frac{3h}{3Ld - 4d^2} \Delta z \tag{6}$$

where p_e is the effective photo-elastic constant (~0.22) of the fiber material and Δz is the vertical displacement of the micrometer. Therefore, the Bragg wavelength of the fiber Bragg grating is tuned by changing the vertical position of the micrometer.

The simulation results of Eq. (6) are shown in Fig. 3 (a,b). The effects of the distance of the load from the end (d) and the length (L) of the beam on the tuning sensitivity are shown in Fig. 3 (a) for a fixed thickness (h) of 5 mm. Fig. 3 (b) shows the dependence of the tuning sensitivity on the thickness (h) of the beam and the distance of the load from the end (d) for a fixed length (L) of 80 mm. It can be seen that the length (L) of the beam should be reduced and its thickness should be increased in order to obtain broader-range tunability. Another way to increase the tuning range is by reducing the distances of the two forces from each end, i.e. d. Therefore, the tuning range can be optimized by choosing proper values of these parameters. For example, the tuning sensitivity of 32.97 nm/mm can be achieved with a beam of h= 10 mm, L=80 mm and d=5 mm. With this beam, 164.85 nm maximum tuning range can be achieved by a standard 5 mm micrometer. On the other hand, with a beam of h=5 mm, L=100 mm and d=25 mm, the tuning sensitivity is only 3.62 nm/mm which is around 9 times smaller than the above. Thus a thick, short beam and small distances of applied forces from each end are preferred.



a

b

Fig 3. (a) The effects of beam length (L) and distance of the load from the end (d) on the tuning sensitivity of FBG (b) The effects of beam thickness (h) and distance of the load from the end (d) on the tuning sensitivity of the FBG.

3. Experimental results and discussion

The experimental setup is shown in Fig. 4. A FBG was written on a hydrogen-loaded fiber with an excimer laser using a phase-mask technique. The FBG was then annealed at 80 ^{o}C for 4 hrs in an oven to drive out the hydrogen atoms residing within the fiber. The original

3-dB bandwidth and the Bragg wavelength of the FBG were 0.2 nm and 1541 nm, respectively. The FBG was epoxy-bonded onto the top surface of a rectangular beam, having the thickness, width and length of 5 mm, 20 mm and 100 mm, respectively. The bending of the beam was achieved by translation of a movable block, which was driven by a micrometer screw of 20 mm travel range and 10 µm resolution. The positions of the two loads were at equal distances of 25 mm from the ends of the beam. Light from a broad-band amplified spontaneous emission (ASE) source (Opto-Link OLS15CL) illuminated the FBG through an optical fiber circulator. The optical fiber circulator directed the light from port 1 to port 2 to the FBG. The reflected light was redirected by the circulator from port 2 to port 3 to an optical spectrum analyzer (OSA) (ANDO AQ6317B) where the waveform was displayed and analyzed. It can be assumed that the whole setup worked in a constant temperature environment because the experiments were conducted under laboratory conditions. Therefore, the shift in the Bragg wavelength of the FBG was not affected by temperature fluctuation effects and thus was linearly proportional to the strain along the beam.

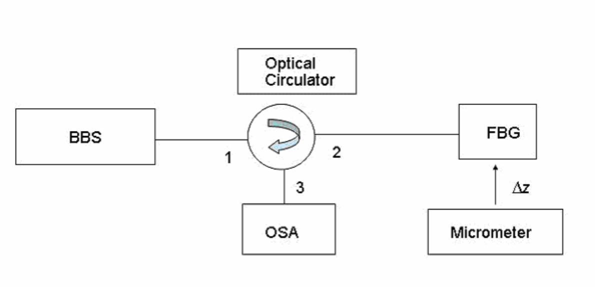
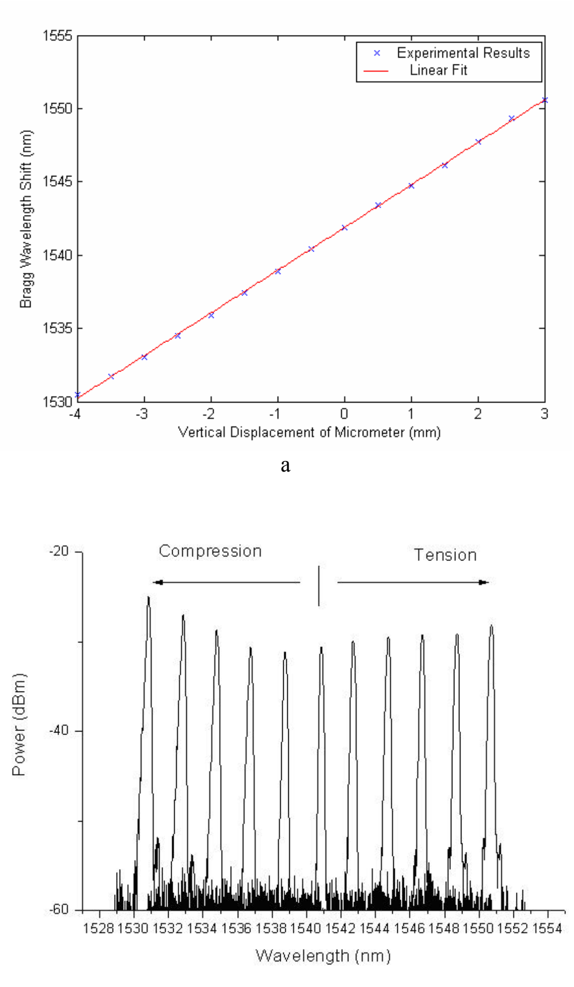


Fig. 4. Experimental setup (Δz: vertical displacement of the micrometer; FBG: fiber Bragg grating; BBS: broad band source; OSA: optical spectrum analyzer; 1, 2 and 3: port numbers of the optical circulator).

The Bragg wavelength shifts of the FBG were recorded for different vertical positions of the micrometer as shown in Fig. 5(a). The Bragg wavelength shift was directly proportional to the displacement of the micrometer and a tuning sensitivity of 2.911 nm/mm was achieved. Fig. 5(b) shows the spectral responses of the FBG across the tuning range. When the micrometer was tuned by 7 mm, the Bragg wavelength continuously shifted from 1530.5 nm to 1551 nm, which resulted in a total spectral range of 20.5 nm. The variations of the reflectivity were due to the unflattened ASE spectrum. The changes of 3-dB bandwidth of the FBG spectrums are shown in Fig. 6 when the FBG was being tuned across the tuning range from 1530.5 nm to 1551 nm. This shows that the FBG is chirp free when it is being tuned.



a

b

Fig. 5. (a) Bragg wavelength shift versus vertical displacement of the micrometer (b) Reflection spectrums of the FBG..

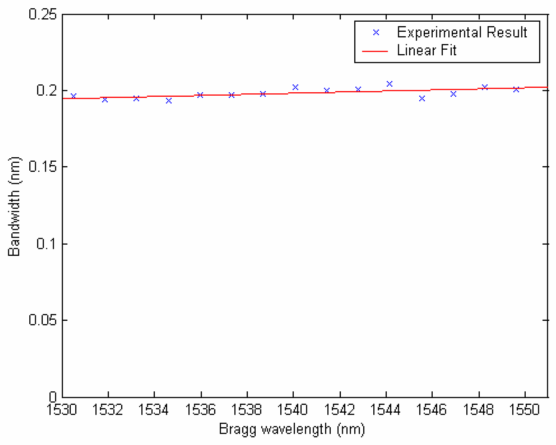


Fig. 6. 3-dB bandwidth of the FBG reflection spectrums versus Bragg wavelength.

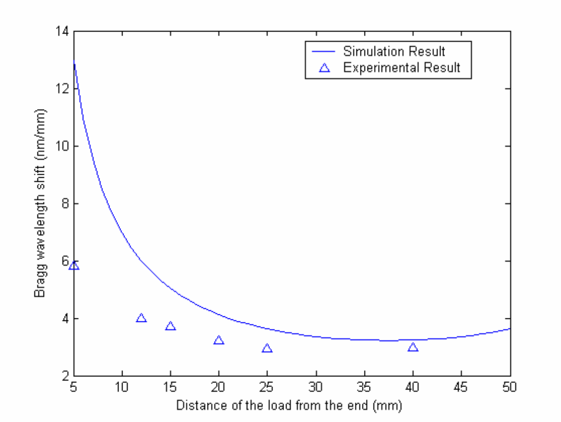


Fig. 7. Tuning sensitivity of Bragg wavelength versus position of applied load from the end (d).

The simulation and experimental results are shown in Fig. 7 by changing the value *d*. It can be seen that the broader tuning range can be obtained by applying the loads near both ends, i.e. smaller value of *d*. For instance, the tuning sensitivity were 5.8 nm/mm and 2.96 nm/mm when the values of *d* were 5 mm and 40 mm, respectively. The discrepancies between the theoretical and experimental results are mainly due to non-rigid coupling between the fiber, epoxy and beam.

4. Conclusions

A setup of a non-chirped Bragg wavelength tuning mechanism has been demonstrated. A simple rectangular beam was used as the FBG carrier in order to generate a uniform strain along the grating for tuning the Bragg wavelength linearly. A tunable Bragg wavelength ranging from 1530.5 nm to 1551 nm has been achieved by changing the vertical displacement of the micrometer of 7 mm. This tuning device is simple in configuration, low cost and easy to operate. This can be used in various optical components, such as tunable filters, tunable fiber lasers, dynamic add-drop demultiplexers, etc.

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