Tuneable optical filter based on a Fibre Bragg Grating with USB interface

D. S. Fernandes, L. M. Pessoa and H. M. Salgado

***Abstract*— This paper describes the theory, design and implementation of an optical tuneable filter, controlled by LabView through an USB connection. The tuneable filter system is based on a piezoelectric actuator which works by compressing the fiber Bragg grating. A high-voltage amplifier was also developed for driving the actuator. The optical filter is suitable for channel demultiplexing within WDM systems.**

***Index Terms*— Bragg gratings, tunable filters, optical filters.**

I. Introduction

FIBER Bragg gratings (FBGs) consist of a periodic modulation of the refractive index along the fiber core as a result of exposure to intense UV light. The most common writing technique is the use of a phase mask. FBGs act as selective filters, the wavelength in resonance with the modulation period being given by the Bragg condition:

$$\lambda_B = 2\Lambda \cdot n_{eff} \tag{1}$$

The dependence of the Bragg wavelength with the refraction index (*n*) and the modulation period (Λ) is described by the following differential relationship [1]:

$$\Delta\lambda_B = \lambda_B \left(\frac{\Delta n_{efc}}{n_{efc}} + \frac{\Delta\Lambda}{\Lambda} \right) \tag{2}$$

such that any external quantity changing any of the parameters will induce a shift in the central Bragg wavelength. These changes can be made either through temperature variation (refractive index change) or mechanical strain (period change). This makes FBGs well suited for applications such as optical filters and sensors. Tuning of the Bragg wavelength can be achieved thermally using a Peltier element. A shift of 0.8 nm for every 60°C of temperature variation (13.48pm/°C), but with limited tuneability (3 nm), has been reported [1]. A broader tuning (up to 10 nm) has been achieved by coating the FBG with a resistive thin film whereby the temperature is increased by *Joule* effect. With this method temperatures as high as 800°C [2] may be attained. On the other hand, taking into account the good stress and strain properties of silica fibers, and since silica is 23 times stronger under compression than under tension [3], compressive stresses have been preferentially selected to achieve large tuning ranges. The shift of the Bragg central wavelength peak, $\Delta\lambda_B$ as a result of application of stress is described by the following equation [4]:

$$\frac{\Delta\lambda_B}{\lambda_B} = (1 - p_e) \cdot \epsilon_Z \tag{3}$$

where $\epsilon_Z = \Delta L_Z / L_Z$ is the axial strain and $p_e = 0.22$ is the photoelastic coefficient, which implies a negative contribution to the wavelength shift due to a change in the refraction index. Furthermore, since the maximum allowable strain admissible in commercial fibers is 4% (40000 $\mu\epsilon$), the theoretical maximum tuning range in the 1550 nm window is approximately 50 nm.

In this paper a Bragg grating compressed by a piezoelectric transducer (PZT) with a response time in the order of milliseconds is described.

II. Device description

A special steel frame has been designed and realised. The piezoelectric actuator is screwed within this frame and connected to a system of ceramic FC ferrules. Two ferrules with 125 μm of internal diameter were used, one mounted to a fixed stage and the other one connected to the PZT. The ferrules were used to accurately compress the fiber along its axis and prevent it from buckling. This is achieved by confining as much of the fiber as possible within the precision ferrules, thus providing a guiding system which is aligned by a ferrule sleeve. Micro and macro bending are so minimized, as well as the probability of breaking the fiber. The FBG was glued between the ferrules with a total distance of approximately 2 cm. Even so, there is always a certain portion of the fiber which will remain unguided. Iocco *et al* [5] found the maximal allowable length without bending of an unguided fiber (L_{cr}) during compression, based on the buckling theory of columns:

$$L_{cr} = \frac{\pi \cdot r}{2 \cdot \alpha} \cdot \sqrt{\frac{L}{\Delta L}} \tag{4}$$

where $r = 0.0625$ mm is the fiber radius and α is a constant factor which for a column fixed at both ends is equal to 0.5. For a large value of strain, e.g. 3.2 % (32000 $\mu\epsilon$), this equation gives $L_{cr} = 1$ mm. Since this value is relatively high, the tolerance in the positioning of the gap between the ferrules is not critical.

An high voltage amplifier to drive the PZT was also developed. Once the PZT electrically behaves like a pure capacitance (about 130 nF) to the driving amplifier, high currents are

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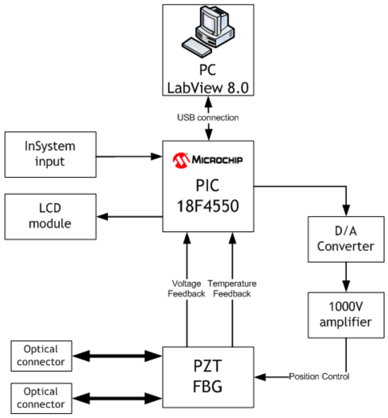

Fig. 1. General diagram. Thin line: electrical connections. Thick line: optical connections.

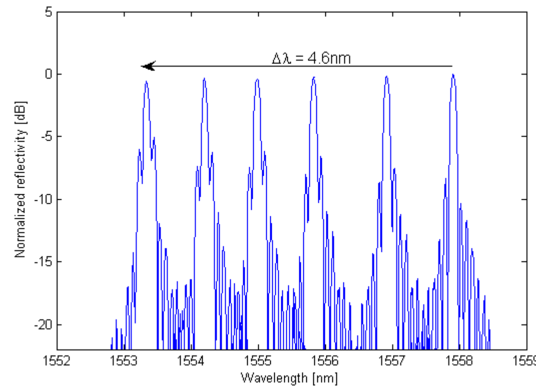

Fig. 2. Reflection spectra of the compressed FBG.

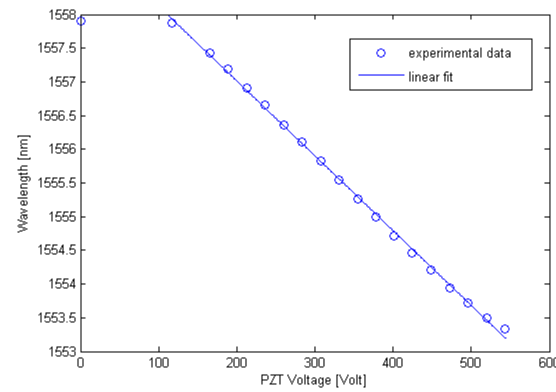

Fig. 3. Bragg grating wavelength shift versus piezoelectric actuator voltage.

necessary to charge and discharge it quickly. On the other hand they require high voltages (1000 V) in order to attain effective displacements. Therefore, the list of available transistors is very restricted, in particular, there isn't any P type transistor for that voltage. For that reason the amplifier has to operate in a single-ended topology. It uses an operational amplifier connected in a negative feedback configuration. Therefore, this mechanism of feedback provides improved control of the amplifier output.

The USB communication is established between the PIC microprocessor and the computer running LabView. The computer sees a virtual serial port in which LabView writes and reads all the information. A unique and specific communication protocol was developed, integrating code error correction capabilities. The device also supports stand-alone operation, featuring an encoder, two press buttons and a LCD panel in the front panel.

III. Experiment

Before compression, the central Bragg wavelength was at the wavelength of 1557.9 nm and the grating was 10 mm long. Figure 2 shows that the maximum negative shift achieved was 4.6 nm. Minor spectral changes were also observed, either in the reflectivity of the Bragg wavelength and the side lobes. The difference in the peak of reflectivity between the original (uncompressed) spectrum and the one corresponding to maximum compression was less than 0.6 dB.

Figure 3 describes the variation of the Bragg wavelength with the applied PZT voltage. The wavelength corresponding to zero voltage was not included in the linear fit because its value clearly does not fit the general behavior of the rest of the experimental data. This is probably explained due to some backlash still existing in the steel frame system which will be refined in future improvements. The slope of the linear fit is m=-11.105 pm/Volt. The range of PZT voltage was limited to 550 Volt because at this voltage the ferrules started touching each other, due to the very reduced length of the gap left between them when the steel frame was assembled.

IV. Conclusion

An optical tuneable filter was proposed and demonstrated. The spectral characteristics of the architecture were presented. The operation of the device has been experimentally tested. The tuning range is to be improved in the forthcoming experiments, by means of using smaller ferrules to compress a reduced length of fiber and by leaving a larger gap between the ferrules in order to take complete advantage of the PZT displacement range. A better spectral response more ssuited to WDM demultiplexing may be obtained with the use of an apodized fiber Bragg grating.

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