Tunable Birefringent Phase-Shift Induced in Fiber Bragg Grating by a Shape Memory Alloy Ferrule

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Abstract *We present a new method to induce low loss tunable birefringent phase shifts in fiber Bragg grating by applying mechanical stresses at precise locations along the FBG with a specially designed shape memory alloy ferrule.*

Introduction

Phase shifted fiber Bragg gratings (PSFBG) are very compact devices that can be used as ultra narrow filter in DWDM system or as Fabry-Perot cavity in the design of distributed feedback fiber laser (DFBFL). This type of laser is of great interest for dense wavelength division multiplexing (DWDM) systems and sensing applications, because of the possibility of single polarization and single frequency operation.

In this paper, we propose a new way to induce tunable phase shifts in FBG. The method uses a shape memory alloy ferrule to apply compressive stresses at precise locations along the FBG, without the need for gluing the fiber. The small footprint of the shape memory alloy (SMA) ferrule allows placing several independent phase modulators along the FBG. This can lead to tunable multiple channel filters as well as Q-switched multiple wavelength DFB lasers.

Theory

Previous works were reported on the possibility of inducing a tunable phase shift in optical fiber based on the use of mechanical stresses. Generally, a tensile stress is applied on a short section of the fiber by gluing it to a magnetostrictive alloy rod[1] or a piezoelectric stack[2]. These methods induce non negligible losses in the transmitted signal and they suffer from a lack of resistance to aging because of the use of glue to fix the fiber to the actuator.

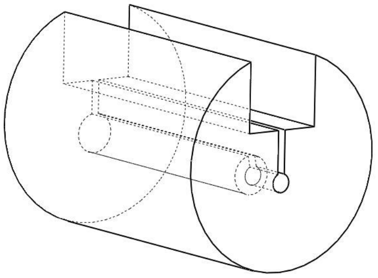

Fig. 1: PhasOptx shape memory alloy ferrule Optimend^{TM}

Recently, the company PhasOptx inc. developed a SMA ferrule that allows the application of high radial stresses on an optical fiber without damaging it. This miniature SMA ferrule (2 mm X 1.4 mm) acts as an all fiber phase modulator and can be incorporated into any optical fiber design without inducing significant loss (< 0.01 dB). The design of the ferrule is shown on figure 1.

The SMA ferrule is manufactured from a copper based SMA wire. After the wire is cut in small cylinder pieces, a hole and a slot are made in the axial direction (see Fig. 1). The slot is used to enlarge the diameter of the hole, in order to enter the optical fiber. Because the diameter of the hole is made slightly smaller than the optical fiber, the conduit exerts stresses on the optical fiber when it closes. These stresses cause the fiber to contract in the radial direction and to expand axially. Because the radial stresses are not perfectly uniform, the radial contraction is different for the two orthogonal transverse directions. This behavior thus creates a birefringent phase shift in the optical fiber. The amplitude of the accumulated phase shift is given at equation (1), where k_0 is the wavenumber, $\bar{n}$ is the effective index of the undisturbed fiber, $\Delta\overline{n_{x,y}}$ is the effective index change in each direction, L is the length of the stressed fiber section and ΔL is the elongation of the fiber stressed section in response to the applied stress.

$$\Delta\varphi_{x,y} = k_0\left(\bar{n}\Delta L + \Delta\overline{n_{x,y}}(L+\Delta L)\right) \qquad (1)$$

The value of the refractive index change $\Delta\overline{n_{x,y}}$ depends on the induced stress in the fiber core.

Numerical simulation

Using the software Cosmos Works, we compute finite elements numerical simulations of the behaviour of the SMA ferrule when it closes on the optical fibre. We found that the closed ferrule induces compressive stresses in both orthogonal directions in the fiber core. This behaviour is different than what we can observe for a purely lateral compression, i.e., a compressive stress in the direction of the applied load and a tensile stress, three times smaller, in the perpendicular direction. The ferrule thus creates a positive retardation of the optical phase in both orthogonal directions.

Using the coupled mode equations, we perform numerical simulations of the transmission of the PSFBG. To do this, we compute the transmission of a FBG with a section submitted to stresses in the core. The stress required to obtain a π/2 optical phase shift is approximately 117 MPa in each direction, for a simulated compressed section length of 300 µm. As these stresses are of the same order of magnitude than the stresses calculated by the finite elements numerical simulation, we can expect that the SMA ferrule can create this kind of phase shift in the optical fiber.

Experiments

We place a SMA ferrule of the design shown in figure 1 approximately in the middle of a non-chirped apodized FBG. By slowly opening the ferrule with a micrometric screw while looking at the transmitted signal displayed by the optical vector analyser (LUNA model OVA-CTe), we can tune the amount of phase shift experienced by the optical wave. Using this procedure, we have tuned the phase-shift in order to get a π/2 optical phase-shift for one of the two orthogonal polarization states. The results are shown in figure 2 where we can see the undisturbed FBG transmission spectrum for an average of all polarization states and the PSFBG transmission spectrum for two orthogonal polarization states oriented with the fast and slow axis of the birefringent fiber section. The loss induced by the SMA ferrule to the transmitted signal was measured below 0.01 dB for a π/2 optical phase-shift.

The presence of two peaks for the dashed curve is probably caused by a rotation of the birefringence axis when the ferrule closes on the fiber. The FWHM of the central peak is 4 pm while the FWHM of the undisturbed FBG is about 83 pm.

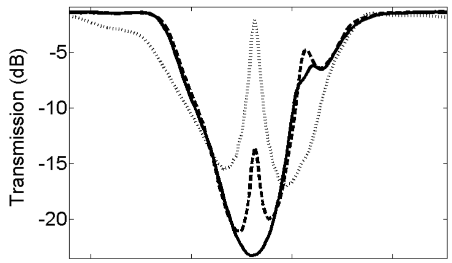

Fig. 2 : Transmission spectra of the FBG with an Optimend for polarization state one (dotted curve), polarization state two(dashed curve) and without an Optimend (solid curve).

To investigate the evolution of the phase shift with the position of the opening lever, we plot the transmission spectra of the PSFBG for three different positions of the lever. The two peaks for each curve correspond to the two orthogonal polarization states that experienced two different phase shifts. For the three different positions, the wavelength difference between the two peaks are separated by 31.4 pm, 34.0 pm and 41.8 pm respectively. These wavelength differences correspond to birefringence of 2.98 X 10^{-5}, 3.22 X 10^{-5} and 3.96 X 10^{-5}, respectively.

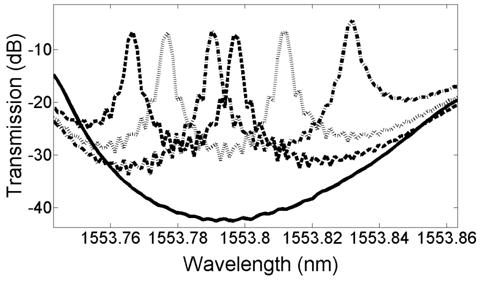

Fig. 3: Transmission spectra of the PSFBG for 3 positions of the opening lever(position 1 - dashed curve, position 2 – dotted curve, position 3 – dash-dot curve) and transmission spectra of the undisturbed FBG (solid curve)

These values of birefringence should be high enough to enable single polarisation operation of a DFB laser and small enough to enable rapid changing of the polarisation state of the laser.

Conclusions

We demonstrated the possibility of inducing a localized birefringent phase shift in fiber Bragg gratings by the use of a shape memory alloy ferrule. The amplitude of the phase shift can be tuned by controlling the position of the opening lever. We measured the transmitted and reflected signal from the PSFBG and the results agreed well with the simulations. Since the proposed method induces negligible losses in the optical fiber and is applicable to any kind of fiber, we believe that it can have a great potential for the development of single polarization Q-switched DFB fiber lasers and tunable narrow pass-band filter.

Our next efforts will be placed towards using a piezoelectric actuator to drive the opening lever and thereby control dynamically the induced phase shift.

References

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