Raman pump induced group delay switching in non-permanent phase-shifted chirped fibre Bragg gratings

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A temporary phase-shift can be locally created in a chirped fibre Bragg grating thanks to a NiCr wire. Changing the bias current value modifies the phase-shift (around π), which allows to switch between a positive and negative delay variation at a specific wavelength. This mode of operation is rather slow and to overcome this limitation, we propose to exploit the photothermal effect. Using an optical pump emitting outside the grating spectral region, we perturb the phase-shift value fixed around π. The results demonstrate that the group delay can be all-optically tuned over a wide range and with relatively low optical powers.

Introduction

Controlling the group delay and/or group velocity of optical pulses has attracted considerable attention in the past recent years, especially in the frame of ultrafast optical communications and microwave photonics. Among the means investigated to achieve this goal, the control of light dispersion properties using fibre-based photonic structures has been widely investigated. In particular, fibre Bragg gratings (FBGs) have been used for tuneable delaying of picosecond pulses, either by a frequency-shift induced through a thermal or mechanical actuation [1,2] or via the nonlinear Kerr effect [3,4]. Switch between subluminal and superluminal pulse reflection has also been observed in active FBGs associated to Er/Yb doped fibre and subject to optical pumping of several hundreds of mW [5,6].

In a recent work, we have demonstrated the possibility to tune the group delay of a chirped FBG (CFBG) written in standard singlemode fibre through the creation of a temporary phase-shift introduced locally by a wire heater [7]. The remarkable feature of our setup remains its capability to switch between strong delay or advancement depending on the phase-shift value, which is particularly attractive for the implementation of simultaneously wavelength and delay-tuneable devices. Instead of switching by modifying the voltage applied to the wire, we exploit here the photothermal effect. Using an optical pump emitting outside the grating spectral region, we perturb the phase-shift value fixed around π, which in turn locally affects the group delay and allows us to switch between negative and positive delay variation. The results demonstrate that the group delay can be all-optically tuned over a wide range and with relatively low optical powers.

Experiments and results

Our experiments were carried out on a 10 cm-long linearly chirped FBG written into hydrogen-loaded singlemode fiber through a 1070.040 nm-central period phase mask. Its chirp coefficient is 49 pm/cm. As shown on Fig.1, the CFBG reflection spectrum is centered on 1548.2 nm and presents a 3 dB bandwidth of 0.71 nm while its dispersion is about 1400 ps/nm. The grating was not apodized, which explains the relatively strong ripple on the group delay curve in the reflection band. All measurements were carried

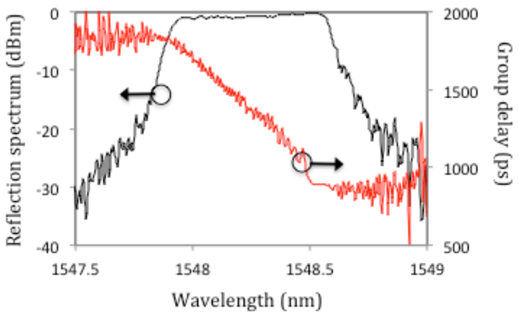

Figure 1: *CFBG reflected spectrum and associated group delay evolution (light launched through the long-wavelength port).*

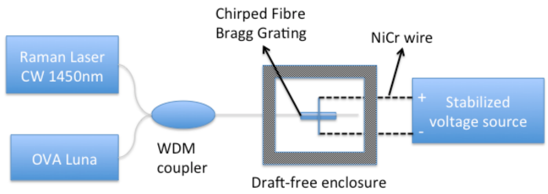

Figure 2 : *Sketch of the experimental setup used to control and measure the group delay variation.*

out using the optical vector analyzer (OVA) CTe from Luna Technologies with the best wavelength resolution (1.25 pm).

Figure 2 displays a sketch of the experimental setup. A NiCr (nickel-chrome) wire heater with an outer diameter of ~0.3 mm is placed perpendicularly to the stripped CFBG. A voltage source and a variable resistor are used to control the temperature of the wire. Due to the thermo-optic effect, the refractive index of the fibre locally varies with the temperature of the wire heater. As a result, a phase shift is introduced in the corresponding region of the grating [8]. The phase shift value is directly linked to the applied voltage and therefore to the temperature of the wire. The grating and the wire heater are placed in a draft free enclosure to ensure stability. A Raman laser centered on 1450 nm (i.e. well below the CFBG reflected spectrum) was used for achieving a photothermal tuning of the FBG similar to [9]. Practically, the Raman pump allows us to exploit the large broadband absorption (non-resonant light) resulting from the grating photo-writing process in the hydrogen-loaded fibre, which locally heats the grating and shifts its resonance condition via the thermo-optic coefficient. As shown below, we use this light to modify the sign of the group delay variation induced by the wire. Its light is launched through a WDM coupler into the fibre containing the CFBG. The OVA then analyzes the CFBG reflected spectrum.

Figure 3 depicts the reflected amplitude and group delay evolutions when a 0.2 mm-wide region of the grating is heated. The voltage applied to the wire (U_{Th}) was modified to address different phase shift values. For a voltage increase of about 0.9 V, the phase shift locally grows from zero and overpasses π. For phase shift values below π, the group delay variation is positive while for phase shift values higher than π, the evolution is negative. In both cases, the 3 dB bandwidth of the notch is ~5 GHz, which is common for phase-shift devices. The obtained behaviour is consistent with numerical simulations carried out using the coupled mode equations. During its growth, the central wavelength of the notch shifts. In our experiments, the maximum wavelength shift obtained by varying the phase shift from 0 to more than π has been measured to be equal to 30 pm.

This is attributed to the local temperature elevation. In addition, the CFBG bandwidth slightly increases (a few pm) as the higher reflected wavelengths are shifted due to the phase shift. It is also worth to mention that one can modify the operating wavelength by moving the wire along the CFBG. Hence, such a system allows both wavelength and delay tuning. Figure 3 also demonstrates the possibility to accurately tune the group delay variation, either positively or negatively. In particular, it shows that the induced delay variation can reach values higher than the delay excursion offered by the CFBG

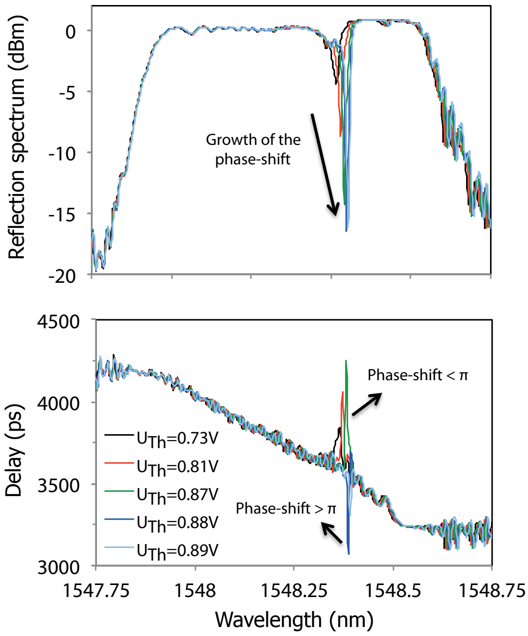

Figure 3 : *CFBG reflected spectrum and group delay evolution for different thermally-induced phase shift values*

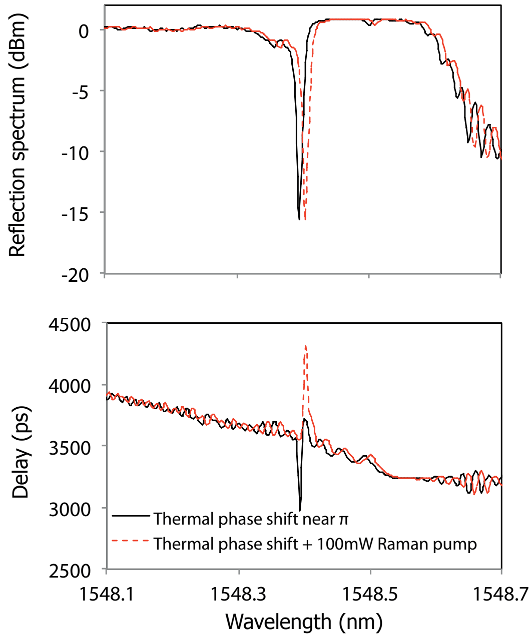

Figure 4 : *Switch between negative and positive delay variation using 100 mW Raman pump.*

and even larger than those corresponding to the physical length of the device, which is quite remarkable. This eventually means that the group index of the device can be turned superluminal (<1) and even negative in the situations of strong advancement.

In practice, switching with the applied voltage remains a slow process (several seconds to reach the stability) as it results from a local temperature elevation. To speed up the switching process by several orders of magnitude, we have used a Raman laser allowing us to profit from the photothermal effect. In our experiments, the voltage source was set to obtain a thermally-induced phase shift slightly above π (plain curve of Fig. 4). Then, the Raman laser was switched on with an average power equal to 100 mW. Thanks to the broadband absorption band resulting from the grating inscription process (generally of the order of 10 % of the transmitted power), the injected pump power was sufficient to perturb the phase shift value and to switch to positive group delay variation (dashed curve of Fig. 4). By switching off the pump, the phase shift retrieved its preliminary value. To ensure proper switching conditions, the initial phase shift has to be slightly above π. This comes from the fact that, as the photothermal effect induces a slight wavelength shift (4 pm with the power used in our experiments), the voltage applied to the wire is no longer sufficient to yield a phase shift above π at the operating wavelength. It becomes slightly below π, resulting in a reversal in the group delay variation.

As shown in Fig. 3 and 4, the wavelength range in which the phase-shift occurs is characterized by a strong amplitude decrease. In practice, this amplitude distortion can be drastically attenuated by locally heating two closely-spaced sections of the CFBG, as already demonstrated in [7]. In practice, thanks to the induced wavelength shift, one can use the first heated region to decrease the amplitude spectrum variation on the second one, while keeping constant the group delay variation. Such a configuration can be advantageously used, especially in a double pass configuration, which allows to double the generated delay variation [10].

Conclusion

We have experimentally demonstrated that the group delay curve can be tightly controlled in thermally-induced phase-shifted CFBGs. A wide-range tuning between positive and negative group delay variations has been reported in a band of a few GHz, which is particularly interesting for group delay control issues. The possibility to diminish the response time of the system has also been reported thanks to the use of Raman laser emitting outside the CFBG reflection spectrum. The reported device can be of interest in microwave photonics applications requiring tuneable time delays over bandwidths of a few GHz.

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