Component for Optical PMD-Compensation in a WDM Environment

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Abstract: We demonstrate a device exhibiting an adjustable amount of PMD ranging from 0 to 80 ps by stretching a chirped Bragg-grating by 0.1%. The operation bandwidth is 2 nm while other wavelengths are left untouched.

Introduction

Polarization mode dispersion (PMD) has become a serious problem in optical communication limiting either bit-rate or transmission distance severely. Numerous concepts have been presented to overcome this limitation [1-4]. Most of these concepts offer PMD compensation on a per-channel basis, because the compensation bandwidth is strongly limited. Hence in a WDM environment, the channels would have to be demultiplexed before each channel is individually compensated for PMD. In this paper, we demonstrate a variable polarization delay line (VPDL) which exhibits an adjustable amount of PMD within its operating bandwidth. For wavelengths outside this bandwidth the device does not show any PMD and is either transparent or reflective. This offers the possibility to cascade several of these devices in a WDM environment while each device affects only one single channel.

Principle of Operation

The VPDL consists of a four-port polarization beam splitter (PBS) and a linearly chirped fiber Bragg grating (FBG), see Fig. 1. The incoming light is split into two orthogonal polarizations (denoted H and V) travelling forward and backward into the grating. The reflected light travels back into the PBS. The polarization controllers PC-S and PC-P are adjusted in a way that the polarization of both reflected signals is rotated by 90 degrees and thus directed to the output port. If both optical paths have the same length, the device is transparent for the operating wavelength and does not disturb the input signal. The reflection point inside the grating can be moved by several millimeters by stretching the grating by a few microns [5]. In that case the optical paths are of different length and the device exhibits a differential group delay (DGD) between the two principal states of polarization.

If the polarization controllers PC-S and PC-P are adjusted in the described way, the light travelling into the grating is forced to be circularly polarized [6]. One is free to choose the polarization to be either left- or right-handed circular. This choice affects the behavior for wavelengths outside the reflection bandwidth and the parameter *m* in the following Jones matrix can be chosen one or zero, i.e. light outside the reflection bandwidth of the grating is either transmitted or reflected.

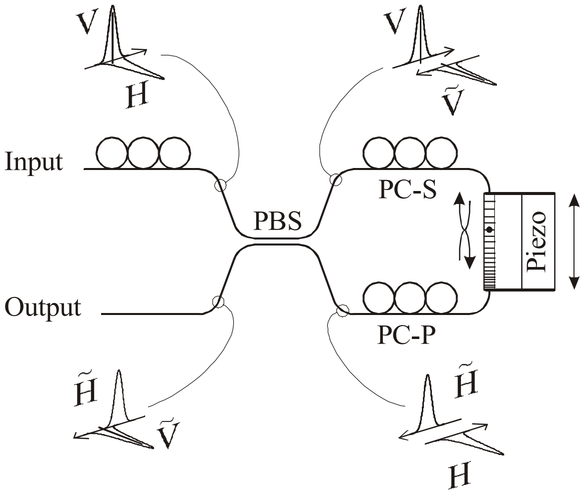
The Jones matrix of the system is given by

$$M = e^{-j2\tau_0\omega}\begin{pmatrix} m\cdot t(\omega,\varepsilon) & r(\omega,\varepsilon)e^{j\varphi(\omega,\varepsilon)} \\ r(\omega,\varepsilon)e^{-j\varphi(\omega,\varepsilon)} & m\cdot t(\omega,\varepsilon) \end{pmatrix}$$

$$\varphi(\omega,\varepsilon) = D\frac{\lambda_0^2}{4\pi c_0}\omega^2(1-\varepsilon) - D\lambda_0\omega\varepsilon$$

where τ_0 is the group delay of the fibers between the grating and the PBS, ω is the deviation from the central angular optical frequency, c_0 is the velocity of light in vacuum and λ_0 is the nominal wavelength. $r(\omega,\varepsilon)$ and $t(\omega,\varepsilon)$ denote the amplitude reflection and transmission spectra of the grating respectively. The parameter D (given in ps/nm) describes the dispersion of the grating. The mechanical strain is given by $\varepsilon=\Delta L/L$. It is obvious that, beside the adjustable amount of DGD, the device exhibits a polarization dependent chromatic dispersion (PCD) defined by D. To avoid distortion due to PCD the grating dispersion D should be chosen as small as possible.

Figure 1: Experimental Setup



Experimental Setup

The mechanical strain is applied to the FBG by means of a piezo driven translator which is able to generate an absolute displacement of 30 µm corresponding to a strain of 0.1% . The polarization controllers PC-S and PC-T are adjusted in a way that the light reflected inside the grating is directed to the output port while other wavelengths are directed back to the input port (*m* = 0). Figure 2 shows the power reflection spectrum of the relaxed grating which is equivalent to the transmission spectrum of the device. The insertion loss of the whole device is about 3 dB and is dominated by connector losses and the insertion loss of the PBS. The group delay curve in figure 2 reveals that the group delay of the grating is not perfectly linear. In the linear region the dispersion of the grating is approximately 40 ps/nm corresponding to an equivalent length of 2.4 km standard single mode fiber.

Figure 2: Power reflection spectrum of the FBG and corresponding group delay.

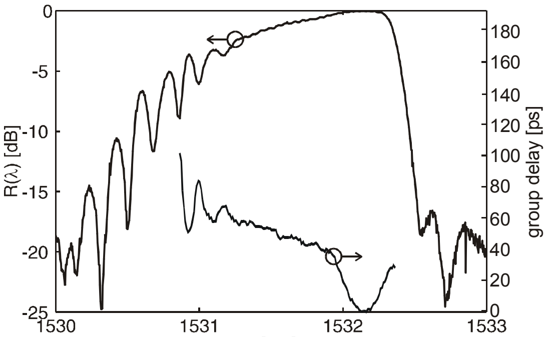
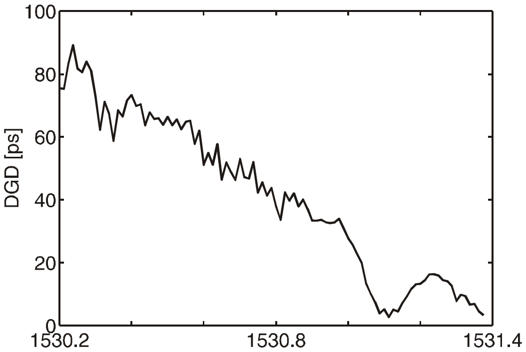


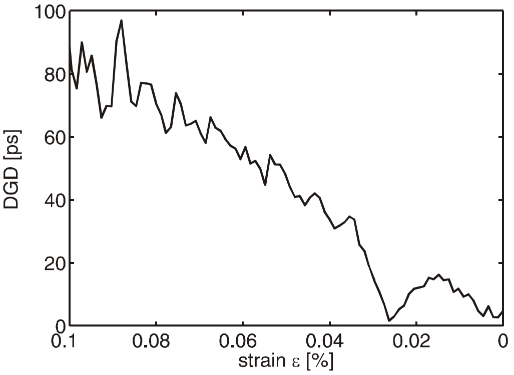
Figure 3 depicts the wavelength dependence of the DGD within the reflection bandwidth of the grating. The measurement has been performed using a Stokes polarimeter and a tunable laser source. The data is evaluated using a slightly modified Jones matrix Eigenanalysis. Between 1530.4 nm and 1531 nm the DGD decreases linearly with wavelength. Between 1531 nm and 1531.1 nm the slope changes. This is in good agreement with the group delay curve of the grating shown in Fig. 2 (the absolute wavelength displacement is due to different environmental conditions). Due to the two-pass configuration the group delay changes are doubled in the DGD curve. The non-linear behavior could be avoided with a grating having a linear group delay curve.

Figure 3: DGD as a function of wavelength.



When the grating is stretched, the amplitude and the group delay spectrum shifts to longer wavelengths. The amount of this shift is linearly dependent on the applied strain (~ 1 nm / mstrain). For PMD emulation or compensation the device is operated at a single wavelength of 1531.4 nm. By changing the strain ε from 0.03 % to 0.09 % the DGD can be continuously adjusted from 0 ps to 80 ps (see Fig. 4). The ripples on the DGD curve are due to the group delay ripples of the grating.

Figure 4: DGD as a function of strain at λ=1531.4 nm.



As explained above, all light outside the reflection bandwidth of the grating can be directed to the output port without adding any PMD (*m* = 1). For this configuration we measured a residual DGD of less than 2 ps.

Discussion

The device offers the possibility to adjust the DGD in a continuous way within a certain wavelength range. The non-linear DGD curve in Fig. 5 could be improved by a better grating. It shall be noted that the state of polarization (SOP) rotates just 27 times around the Poincaré sphere when the DGD is tuned from 0 ps to 80 ps. Free-space PMD emulators rotate the SOP about 15000 times around the Poincaré sphere making these free-space devices unsuitable for concatenation [2]. Therefore the presented device is better suited for higher order PMD generation and adaptive compensation.

Conclusions

We successfully demonstrate the operation of a variable polarization delay line allowing the DGD to be adjusted from 0 ps to 80 ps within less than 10 ms. The device is well suited for WDM applications since it has no PMD for wavelengths outside the operation bandwidth. Higher order PMD can be generated by concatenating several of these devices. Changing the DGD of one single device changes its output polarization very little which makes the device well suited for concatenation.

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