A novel tunable polarization mode dispersion compensator with strain chirped fiber Bragg gratings

Yumin Liu (刘玉敏), Zhongyuan Yu (俞重远), Yuan Zheng (郑 远),
Xiaoguang Zhang (张晓光), and Bojun Yang (杨伯君)

School of Sciences, University of Beijing Posts and Telecommunications, Beijing 100876

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A tunable polarization mode dispersion (PMD) compensator based on strain-chirped fiber Bragg gratings (FBGs) is proposed. It natures in flexible designing, large tuning range, without using linear or nonlinear chirped phase mask, fast tuning response time, continuously adjustable, all-fiber based, compact, and cheap.

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Increasing demand on the data bandwidth in optical fiber communication systems, especially after the fast development of the internet, impels the operating bit rate toward the direction of high speed optical time-division-multiplexing (OTDM) and wavelength division multiplexing (WDM) systems. Polarization mode dispersion (PMD) is regarded as a sever obstacle and ultimate limitation on high-speed long haul optical transmission with a bit rate of 10 Gb/s or beyond[1]. In general, PMD is caused by the different transmission speeds of the signal's two directions of polarization as they propagate along the fiber with a small random birefringence. In the transmission systems, the PMD is a statistically random quantity and can change by the dynamitic path of the network or the environment such as temperature. So an adjustable PMD compensator will quite beneficial. There are several techniques to PMD compensation either in electrical or optical domain with first order. The first order PMD compensation has been extensively researched, while second and higher order PMD compensations are still under discussion[2]. One of the techniques is to splitting the two principal states of polarizations(PSPs) and delay on of them relative to the other in free space, which is very cumbersome. The other techniques are including such as polarization maintaining fiber, high birefringence chirped nonlinear fiber Bragg grating (FBG), and birefringent LiNbO3 waveguides etc.[3]. Among the above techniques, the nonlinear chirped FBG is very attractive to researcher for the continuously adjustable, all-fiber based, and compact. But the drawbacks are that to make such a grating one must use the nonlinear phase mask that is very expensive, and there are no commercialization of the photosensitive high-birefringence fiber, which limits the volume production and conventional applications. In this paper, we proposed another technique to achieve a tunable PMD compensation. Based on strain-chirped FBG, which consists of two uniform FBGs and a deflecting beam with one fixed end.

As shown in Fig. 1, the wavelength chirp $\Delta\lambda$ of the FBG can be expressed as[4]

$$\Delta\lambda(x) = (1-\rho_e)\varepsilon(x)\lambda_B, \tag{1}$$

where x stands for the grating position along its length, and $\varepsilon(x)$ is the deflection beam induced strain along the x direction. λ_B is the Bragg wavelength of the uniform grating when no strain condition, and ρ_e represents the strain-optical coefficient of the silica fibers, which is a measurement of the strain-optic effect. Generally, the strain-optical coefficient ρ_e is 0.22 in silica fiber. In Eq. (1), we neglect the lateral strain perpendicular to the fiber axis since it is much smaller than the axial strain.

As illustrated in Figs. 1 and 2, the two identical FBGs are glued on the two sides of the deflecting beam with a thickness of t. The neutral axis is defined as the axis that retains its original length when the beam is bent up or down, which is shown in the Fig. 2 with a dotted line. Because one end of the beam is fixed, when the other end is deflecting, the beam will experience an unequal bending moment along the direction of x. This is to ensure the mounted FBG each side has a linear chirped stain across the whole grating length, which is dependent on the local radius of the curvature of the beam. At the same time, the region above the neutral axis will experience compression while the region below the neutral axis is stretched. So when the beam is bent upward, the FBG mounted on the upside will work in compress mode and the FBG mounted on the downside will operation in the extension mode. The strain distribution of $\varepsilon(x)$ can be expressed as

$$\varepsilon(x) = \pm\frac{t}{2R(x)}. \tag{2}$$

The negative sign of Eq. (2) is due to the upside FBG operating in compression mode, whereas the positive sign

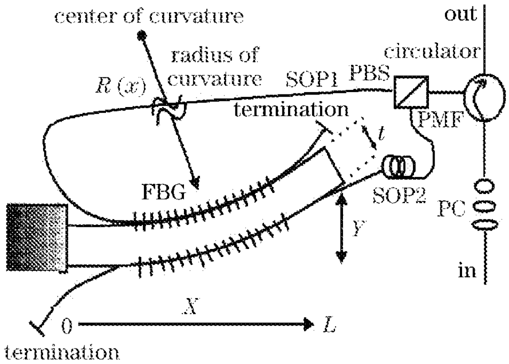

Fig. 1. Structure of the PMD compensator.

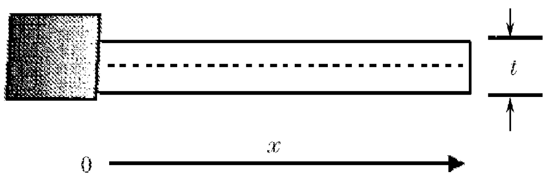

Fig. 2. The side view of the deflecting beam when there is no deformation.

corresponds to the downward FBG operating in extension mode.

Therefore, when two uniform FBGs are mounted on the surface of the beam with a constant width, it can be transformed into two linearly chirped FBGs for the bend induced linear strain gradient along the grating[5]. At the same time the two gratings hold the same chirped characteristics. The differences are that the frequency response of the upward grating of will drift toward the short wavelength, while the downward grating will drift in the opposite direction. So if we use such a device for PMD compensation, we must let the two split signals input in the opposite directions of the two FBGs in order to keep the delay curves of the two FBGs parallel.

We adopts the matrix transmission approach to simulate and discuss the characteristics of the device[6]. This is an effective method for calculating the non-uniform grating structures, which the grating is divided into a series of piecewise-uniform gratings and each piecewise grating decides its own transmission matrix used to describe the characteristic of that section of grating depended by the local grating pitch and refractive index modulation depth. This piecewise-uniform approach is ideal for analyzing chirped grating too. In our calculation bellow, the grating length is assumed to be 4 cm, the effective mode refractive index is 1.45, a cosine apodized function is adapted in the two gratings, and refractive index modulation depth is $\partial n = 4 \times 10^{-4}$. The apodized function only imposed on the long wavelength side of the grating for making full use of the delay characteristics of the FBG[6]. The central Bragg wavelengths of the upward and downward grating are 1550.15 and 1549.85 nm, respectively. Because the two gratings all identically expected the central Bragg wavelength, when deflecting the beam the two gratings hold the same reflectivity and delay curves.

As can be seen from Fig. 3, when the chirped bandwidth is 0.3 nm, the spectrum responses of the two gratings are just the same, which means each of the original reflection curves of the upward and downward gratings shifts about 0.15 nm in the opposite direction. With the increasing of the chirped bandwidth, the two delay curves will separate form each other, and the difference group delay (DGD) of the tow PSPs can be tunable form zero to a large amounts as shown in Figs. 4 and 5, but the crossed section of the reflectivity spectrum is almost 0.3 nm for the tuning directions are opposite and the central Bragg wavelengths of original gratings are separated about 0.3 nm. In the crossed section of the reflectivity spectrum the two delay curves are almost parallel, so the DGD is almost wavelength independent.

The relationship of the DGD and the chirped bandwidth is shown in Fig. 6, where we make the 0.3-nm chirped bandwidth as the start tuning point because at that point the delay curve begins to separate. When the chirped bandwidth is 0.8 nm, the DGD is almost 250 ps, in fact it is not necessary to produce so large amount DGD in PMD compensation. Generally the tuning DGD is less than 100 ps, so the tuning chirped bandwidth is from 0.3 to 0.5 nm, and this is very easy to realize for such a device[7].

An almost linear tuning curve can be seen in Fig. 6, this feature enables this kind of Bragg gratings device

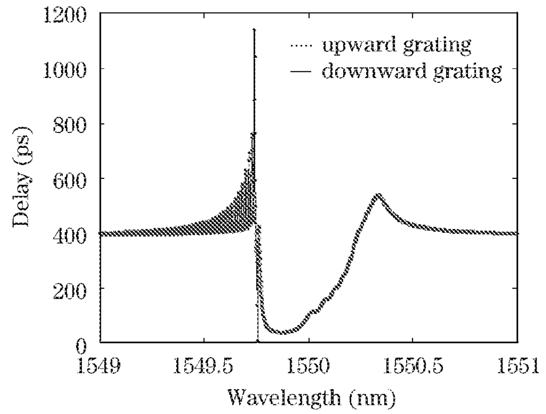

Fig. 3. The delay curves of the two gratings when the chirped bandwidth is 0.3 nm.

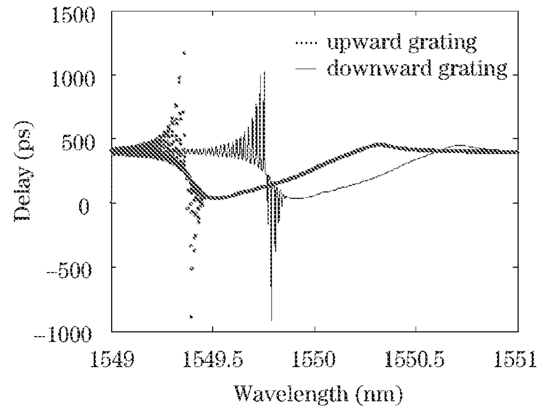

Fig. 4. The delay curves of the two gratings when the chirped bandwidth is 0.7 nm.

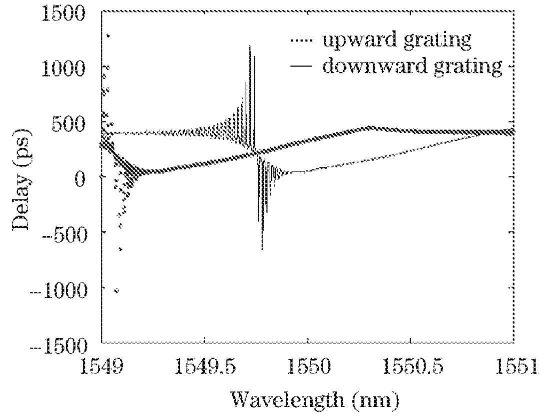

Fig. 5. The delay curves of the two gratings when the chirped bandwidth is 1 nm.

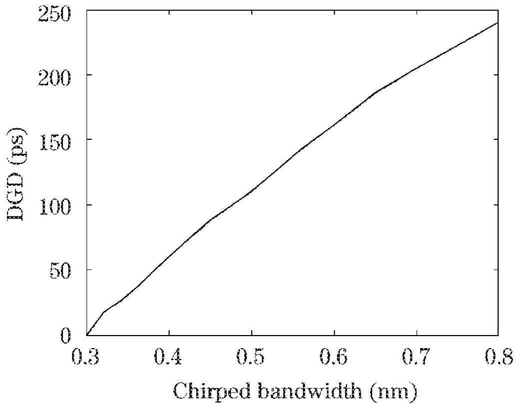

Fig. 6. The tuning curve of the relationship between the DGD and the chirped bandwidth at the central wavelength of 1550 nm.

to be a promising candidate as the tunable PMD compensator.

In conclusion, a novel tunable PMD compensator is proposed by using strain-chirped fiber gratings. The PMD compensation is linear tunable at the carrier wavelength. And the effective bandwidth is almost a const, which can be flexible designed to as a filter at the same time. The tuning is only by deflecting the beam, which means the tuning speed is very fast. Therefore, this PMD compensation technology is a promising candidate for its low cost characteristics.

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