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Novel in-line fiber polarization beam splitter using high-birefringence fiber Bragg grating

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Abstract

This study proposes a novel fiber-type polarization beam splitter (PBS) based on a high-birefringence fiber Bragg grating (Hi-Bi FBG). The reflective and transmitted modes of the Hi-Bi FBG are used to separate the p- and s-waves of an optical signal. The experimental results show that a 36 dB extinction ratio can be obtained in the reflective mode. However, in the transmitted mode, the extinction ratio is just 4.78 dB since the reflectivity of the Hi-Bi FBG is only 34.75%. It is shown analytically that the extinction ratio in the transmitted mode can be improved to 20 dB by specifying a Hi-Bi FBG with a reflectivity of 99%. Finally, it is shown that the Bragg wavelength of the in-line fiber PBS can be tuned electrically to comply with the working wavelength.

Keywords: Fiber Bragg grating; High-birefringence fiber; Polarization beam splitter

1. Introduction

The polarization state of light guided by an optical fiber is an important characteristic in fiber optic communications, optical gyroscopes and interferometric sensors. Obtaining a high accuracy in signal processing or optical measurement applications requires the use of light with well-controlled polarization. In-line fiber polarization beam splitters (PBSs) provide a convenient means of separating launched light into its p-mode and s-mode polarization components, and are more suitable for optical communication systems than bulk-type PBS devices. In-line fiber polarizers are commonly applied in fiber interferometric sensors and are frequently used in polarization-mode-dispersion and high-coherence transmission applications.

Various in-line fiber-based polarization-controlling components have been developed. For example, Ma and Tseng [1] presented a liquid crystal clad fiber polarizer based on a side-polished fiber. In their polarizer, a single-mode fiber was glued in a curved V-shaped groove within a silicon wafer and was then side-polished to a proximity of 0.1 μm from the core. After side-polishing, liquid crystals were dropped onto the polished region. It was shown experimentally that the polarizer achieved an extinction ratio of 42 dB. Diez et al. [2] developed an in-line fiber polarizer based on resonant excitation of the hybrid plasma mode. The device was fabricated by tapering a standard step-index fiber to form an adiabatic taper with a uniform waist. A gold film was then evaporated on one side of the waist to form an asymmetric optical waveguide. In [3,4], the authors demonstrated polarizers with extinction ratios exceeding 30 dB formed by fabricating long-period gratings within Hi-Bi optical fibers. It was shown that the transmission spectra of the in-line polarizers were characterized by a splitting of the loss peaks, thereby enabling the realization of wavelength-selective polarization filters.

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Davis et al. [5] developed a PBS featuring polarization gratings written onto a zero-twist nematic liquid-crystal display. The PBS proved capable of separating diffracted light into two orthogonally polarized orders that either linearly or circularly polarized. Sakamoto et al. [6] presented an All-PANDA-fiber polarization beam splitter/combiner and showed that by coupling two PANDA fibers of appropriate lengths at a suitable alignment angle, the launched light could be separated into two orthogonal polarizations with a crosstalk of less than −25 dB. Zhou et al. [7] reported a near-ideal in-fiber polarizer implemented using 45° tilted fiber Bragg grating structures inscribed in a hydrogenated Ge-doped fiber. The results showed that a polarization-extinction ratio of 33 dB could be achieved over a 100 nm operation range near a working wavelength of 1550 nm.

The present study develops a novel in-line fiber PBS based on a Hi-Bi FBG. By fusing the Hi-Bi FBG to a circulator, the device is capable of splitting the incident light into two orthogonal polarizations regarding to one specific Bragg wavelength. Furthermore, by depositing a thin metal film onto the Hi-Bi FBG [8,9], one specific Bragg wavelength of the in-line fiber PBS can be tuned electrically to enable the device to function over a wider range of working wavelengths.

2. In-line fiber polarization beam splitter

Fig. 1 presents a schematic illustration of the proposed in-line fiber PBS. Since the two orthogonal axes of the Hi-Bi FBG have different refractive indices, the reflective optical spectrum has two different wavelength peaks in the two orthogonal polarizations. When monochromatic light with a wavelength corresponding to one of the Bragg wavelengths passes though the Hi-Bi FBG, s- (or p-) polarization light is reflected, while p- (or s-) polarization light is transmitted. In other words, the PBS separates the launched light into different polarization modes via its reflective and transmitted modes, respectively. As shown in Fig. 1, the in-line fiber PBS is coated with a thin metal film such that the one specific Bragg wavelength in the Hi-Bi FBG can be tuned by the application of an electrical voltage in order to comply with the working wavelength.

In general, a FBG selectively reflects an optical signal in accordance with its Bragg wavelength. The conventional Bragg equation for a FBG has the form

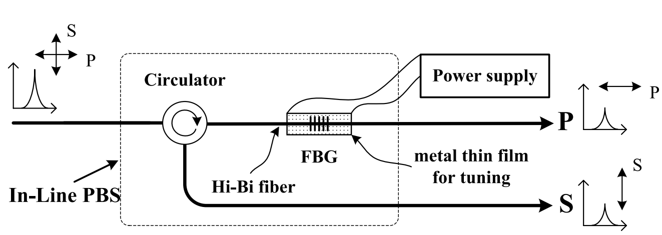

Fig. 1. Novel in-line fiber PBS.

$$\lambda_B = 2n_{eff}\Lambda_B \tag{1}$$

where n_{eff} is the effective refractive index of the optical fiber and Λ_B is the pitch of the Bragg grating. Since the fast and slow axes of a Hi-Bi optical fiber have two different refractive indices, Eq. (1) implies that the FBG will selectively reflect incident light at two different Bragg wavelengths, i.e. λ_{BF} and λ_{BS}, corresponding to the fast axis and the slow axis, respectively.

To characterize the extinction ratio of the in-line fiber PBS, a Gaussian function was used to simulate the reflective spectrums associated with the fast and slow axes of the Hi-Bi FBG [10]. The overall reflectivity spectrum of the Hi-Bi FBG was obtained simply by adding the two spectrums corresponding to the two orthogonal axes, respectively. For analytical convenience, an assumption was made that the intensity of the launched light was unity, with 50% of the light being in the p-polarization mode and 50% in the s-polarization mode. Therefore, the intensities of the p- and s-polarization light reflected from the in-line fiber PBS can be expressed respectively as

$$I_{PR}(k) = 50\%\ R\exp\left\{-\frac{(k-k_{BF})^2}{\sigma^2}\right\}$$

$$I_{SR}(k) = 50\%\ R\exp\left\{-\frac{(k-k_{BS})^2}{\sigma^2}\right\}$$

$$\sigma = \frac{2\pi}{\lambda_{BS,BF}} - \frac{2\pi}{\lambda_{BS,BF}+h} \tag{2}$$

where R is the reflectivity of the Hi-Bi FBG, $k_{BS,BF}$ is the wavenumber corresponding to the Bragg wavelength in $\lambda_{BS,BF}$ ($k_{BS,BF} = 2\pi/\lambda_{BS,BF}$), σ is the peak width parameter, and h is the half bandwidth of the Gaussian distribution at the point where the intensity is $1/e$ of the maximum. In practical Hi-Bi fibers, the characteristic $\Delta\lambda = (\lambda_{BS} - \lambda_{BF})$ is small, and hence the problem of crosstalk arising as a result of the Gaussian distribution of the Bragg wavelengths from the Hi-Bi FBG must be taken into account. In analyzing the crosstalk problem in the current in-line fiber PBS, the extinction ratio in the reflective mode, i.e. ER_R, is defined as

$$ER_R = 10|\log(I_{PR}/I_{SR})| \tag{3}$$

From Eqs. (2) and (3), it can be inferred that the extinction ratio in the reflective mode is independent of the reflectivity, R, of the Hi-Bi FBG. This study simulated the variation in the extinction ratio in the reflective mode with h as a function of $\Delta\lambda$. The two reflective Bragg wavelengths were assigned values of $\lambda_{BF} = 1541.96$ nm and $\lambda_{BS} = 1542.44$ nm, respectively. The simulation results presented in Fig. 2 show that the extinction ratio improves as the bandwidth of the two Bragg wavelengths is reduced or as the separation of the two Bragg wavelengths is increased.

In the in-line fiber PBS, the p-polarization light is reflected by the Hi-Bi FBG at λ_{BF} while the s-polarization light is transmitted. Similarly, the s-polarization light is reflected at λ_{BS} while the p-polarization light is transmitted.