Optical Frequency Discriminator based on Polarization-Maintaining Fiber Bragg Gratings

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Abstract: A novel, fiber-optic optical frequency discriminator (OFD) based on polarization-maintaining fiber Bragg grating is demonstrated. Bias-free linear frequency discrimination with an efficiency of 3.248 V/nm over ~0.2 nm range is demonstrated by employing polarization-assisted balanced detection.

1. Introduction

Optical frequency discriminator (OFD), a device which converts frequency changes to amplitude/intensity changes, finds use in such applications as optical frequency metrology, optical frequency stabilization, coherent optical communications and lidar. Achieving bias-free operation with a wide linear range and a high efficiency is highly desirable for OFD. It is the focus of the current work.

Various OFD configurations have been proposed. They can be categorized as either free-space or fiber-optic configurations. The free-space OFD configurations are very unstable and pose severe angular limitations [1]. Compare to free-space OFDs, the fiber-based OFDs are more stable and have less severe angular limitations [2-4]. The fiber Bragg grating (FBG) based OFD is very compact and robust among different fiber-based OFDs due to its in-fiber resonant structure [5]. However, it suffers from finite DC-bias and a trade-off between efficiency and linearity range.

Here, we present a novel OFD based on polarization-maintaining fiber Bragg grating (PM-FBG), which offers bias-free and linear operation with increased efficiency. PM-FBG contains FBG fabricated inside a PM fiber. Because of the birefringence property of PM fiber, a PM-FBG has two identical reflection profiles with slightly shifted peak wavelengths corresponding to two orthogonal polarizations as opposed to a single, polarization-independent reflection peak of a conventional FBG. This polarization-dependent reflection property of PM-FBG provides a crossover wavelength point where equal amount of powers get reflected along two orthogonal polarization states when input is appropriately polarized. By using this crossover wavelength point as a quadrature point a bias-free, linear and highly efficient OFD is obtained.

2. Principle of operation

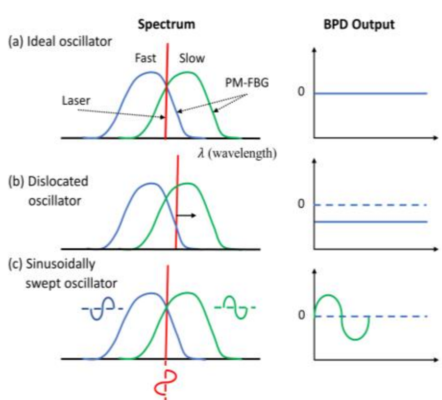

Fig. 1: Operating principle of the PM-FBG based optical frequency discriminator: The reflection spectrum of PM-FBG relative to laser (left) and the corresponding output of BPD (right) for (a) ideal oscillator, (b) dislocated oscillator, and (c) sinusoidally swept oscillator cases.

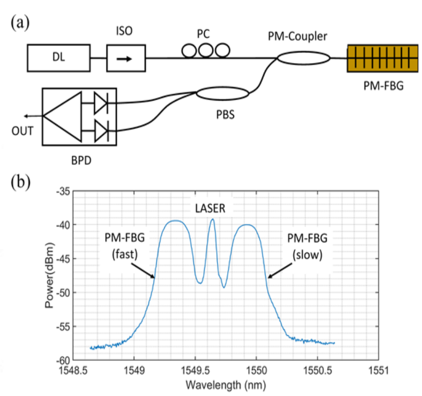

Fig. 2: (a) Schematic of the experimental setup for PM-FBG based OFD. DL: diode laser, ISO: fiber-coupled isolator, PBS: polarization beam splitter, PC: polarization controller, PM-Coupler: polarization-maintaining coupler. (b) Laser wavelength is tuned to the crossover point between two PM-FBG Bragg peaks.

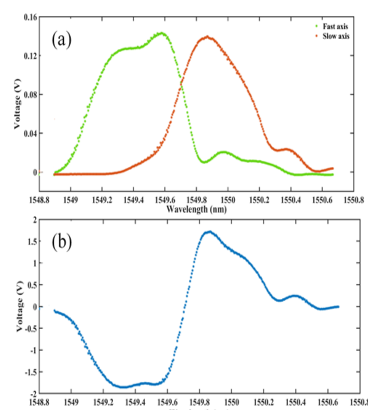

Fig. 3: Experimental trace of (a) two reflection peaks of PM-FBG when input is appropriately polarized and swept across the reflection profile of PM-FBG, (b) balanced output when two orthogonal polarizations are separately detected.

The reflection spectrum from a PM-FBG features two resonance peaks. Their wavelengths are given by

$$\lambda_s = 2\Lambda n_{eff}^s \text{ and } \lambda_f = 2\Lambda n_{eff}^f, \tag{1}$$

where Λ is the grating period, λ_s (λ_f) and n_{eff}^s (n_{eff}^f) are the Bragg wavelength and the effective refractive index for the polarization component along the slow (fast) axis, respectively. Note that n_{eff}^s and n_{eff}^f are nearly equal and so the two reflection peaks are not very far apart.

With this basic understanding about PM-FBG, here is how the proposed OFD works: A proper PM-FBG is chosen so that its two resonances share an overlapping region in the middle of them as shown in Fig. 1(a). An ideal optical oscillator with a single frequency is first tuned to the crossover wavelength between the two Bragg reflection peaks, as illustrated by the left panel of Fig. 1(a). The polarization of the injected optical carrier is adjusted so that equal amount of optical power is reflected by the PM-FBG along its fast and slow axes. The two orthogonally polarized reflection signals are separately detected, and the detector outputs are subtracted from each other to create a *null* (i.e., balanced photodetection (BPD)), as shown in the right panel of Fig. 1(a). Now, when the frequency of an optical signal is dislocated from the crossover wavelength, the reflected powers along the fast and the slow axes change toward opposite directions due to the opposite signs of their corresponding reflectivity slopes. This allows the BPD to generate a large, bias-free response, as shown in the right panel of Fig. 1(b). This is the basic idea of using PM-FBG as an OFD. For example, when optical frequency sweeps sinusoidally near the crossover wavelength, as depicted by Fig. 1(c), the reflected powers along the fast and the slow axes also change sinusoidally but with a 180-degree phase difference which in turn generates a large, bias-free response at the output of BPD.

3. Experiment

An experiment has been setup to verify the performance of PM-FBG as OFD. A layout of the experimental setup is shown in Fig. 2(a). The FBG fabricated on a PANDA-type PM fiber is used. It has two Bragg reflection peaks about 0.6 nm apart, with each peak having a 0.4-nm full width at half maximum (FWHM) (see Fig. 2(b)). A single-frequency, tunable, external-cavity diode laser operating near 1550 nm serves as the light source and its wavelength is tuned to the crossover wavelength of the two Bragg peaks, as shown in Fig. 2(b). The fiber-coupled laser output passes through an isolator before entering a polarization controller. The polarization controller (PC) is used to set the polarization state of the light. A polarization-maintaining 50:50 coupler takes the output of PC to feed it into the PM-FBG and sends the reflected power toward the output. A fiber-coupled polarization beamsplitter splits the two orthogonal polarization modes in the output, feeding them into the two photodiodes of a balanced amplified photoreceiver (Thorlabs PDB 440C). The receiver provides a transimpedance gain of 5.1×10^4 V/A. All the fibers and fiber connectors after the polarization controller are PM type so that the polarization state is preserved.

4. Results

In order to test the linearity of the proposed OFD, we first tune the laser at the crossover wavelength between two Bragg reflection peaks as shown on Fig. 2(b) and adjust the polarization such that a null is achieved at the output of BPD. After that the wavelength of tunable laser is swept at fixed rate of 0.01 second within the reflection spectrum of PM-FBG. Fig. 3(a) shows the trace obtained on an oscilloscope when two polarization states of reflected light are separately detected. Two separate reflection peaks of PM-FBG can be clearly resolved as shown in Fig. 3(a). Fig. 3(b) shows the trace of the balanced output. It resembles standard S-shaped discriminator curve. It can be seen from Fig. 3(b) that nice linear operation has been obtained in ~0.2 nm near crossover point. Moreover, Fig. 3(b) shows the zero DC-bias indicating the bias-free operation near crossover point. Yet another observation from Fig. 3(b) is the slope of 15.467 in the linear range which indicates an efficiency of 3.248 V/nm.

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5. References

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