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Polarization multiplexed dual-loop optoelectronic oscillator based on stimulated Brillouin scattering

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ABSTRACT

A polarization multiplexed dual-loop optoelectronic oscillator (OEO) based on stimulated Brillouin scattering (SBS) is theoretically analyzed and experimentally demonstrated. The narrow bandwidth of SBS gain spectrum is utilized to implement the phase modulation to intensity modulation conversion and select the oscillation mode of the OEO. The polarization multiplexed dual-loop is constructed to suppress the side modes with Vernier effect. The output frequency of the OEO can be tuned by changing the frequency of the signal or the pump light wave. With the polarization multiplexed dual-loop the side-mode suppression ratio (SMSR) of 45 dB is achieved at 10 GHz. The generated oscillation frequency is tuned from 4 GHz to 16 GHz by changing the frequency of the signal light wave. The phase noise decreases with the power increase of the signal light wave when it is under the threshold of SBS. By adjusting the polarization state of the light wave, the influence of the power distribution between the long loop and the short loop on the phase noise of the OEO is investigated. The results show that more power in the long loop is helpful to suppress the near end phase noise.

1. Introduction

Optoelectronic oscillators (OEOs) [1] have attracted great interests for generating microwave signals due to the advantages of high spectral purity and low phase noise with the numerous potential applications, such as in wireless communications [2], optical signal processing [3], radar [4], and modern instrumentation [5]. For a conventional OEO, an electrical filter is usually needed to select the desired oscillation frequency. However, since the electrical filter is hard to be tuned, the tunability of such kind of OEOs is limited. When the electrical filter is replaced by an optical filter, the frequency tunability of the OEOs can be realized easily by changing the wavelength of the laser [6] or the central frequency of the optical filter [7]. Stimulated Brillouin scattering (SBS) can provide narrow band amplification which has a bandwidth as low as tens of MHz [8,9]. It can be applied in an OEO to realize both signal gain and filtering simultaneously [10–13].

In [10,11] the light wave from one laser was split to two paths for the signal and pump light waves, respectively. The output frequency of the OEO in [11] was tuned within 400 MHz by changing the wavelength of the laser with the wavelength dependence of the SBS effect. In order to overcome the frequency tunable range limitation, two lasers can be utilized as the signal and pump light waves, respectively, and by changing the wavelength of the signal laser the output frequency can be tuned in a large range [12]. Within the narrow bandwidth of the SBS gain, there are still several oscillation modes of the OEO due to a relative long fiber used to obtain the SBS gain, which degrades the side-mode suppression ratio (SMSR) of the OEO. The dual-loop configuration with two optical paths and two photo detectors (PDs) was constructed to improve the performance of the SBS-based OEO [13]. However, the dual-loop configuration is relatively complicated because two PDs are needed. In this paper, a polarization multiplexed dual-loop configuration with a polarization-beam splitter (PBS) and a polarization-beam combiner (PBC) is incorporated in the SBS-based OEO. The two loops are directly combined in the optical domain without adding any active electrical devices. The SMSR of 45 dB is achieved at 10 GHz with the polarization multiplexed dual-loop. The polarization multiplexed dual-loop structure was proposed in [14], but the electrical filter was needed to select the oscillation mode, which cannot be tuned in a large frequency band. As fa as we know, it is the first time to incorporate the polarization multiplexed dual-loop in the SBS-based OEO. By changing the wavelength of the signal laser, the generated oscillation frequency is tuned from 4 GHz to 16 GHz. The power distribution between the long loop and the short loop

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is changed by adjusting the polarization state of the optical signal into the PBS and its effect on the phase noise improvement of the OEO is investigated.

2. Operation principle

The schematic of the polarization multiplexed dual-loop OEO based on SBS is shown in Fig. 1. The light wave with the frequency of f_S from the signal laser is sent to a phase modulator, which is modulated by the feedback electrical signal. The modulated light wave goes through an isolator (ISO), and into a high nonlinear fiber (HNLF). The pump laser with the frequency of f_P is injected in the HNLF in the opposite direction through an optical circulator (OC) to provide the SBS gain. The polarization controllers (PC1 and PC2) are used to ensure the polarization alignment between the phase-modulated (PM) optical signal and the pump light wave to obtain the high efficiency of SBS. As shown in the spectrum at point ③ in Fig. 2, the upper sideband of the PM optical signal is amplified by the SBS gain, which interrupts the amplitude balance of the PM sidebands. The unbalanced PM signal with the spectrum shown at point ④ is sent to the PBS via a polarization controller (PC3), by which the power distribution between the two orthogonal polarization paths can be changed. After two different length single mode fibers (SMF1 and SMF2), which compose the short loop and the long loop, the two orthogonal polarization unbalanced PM signals are combined via the PBC and fed to a photodetector (PD). PC4 and PC5 are used in the short loop and long loop to adjust the polarization directions of the two unbalanced PM signals along the two principle axes of the PBC, respectively. The optical to electrical conversion of the two unbalanced PM signals is conducted independently upon the PD due to their orthogonal property. The recovered microwave signals are fed back to the RF port of the phase modulator after amplification by an electrical amplifier (EA). An electrical coupler is inset between the EA and the PD to split part of the microwave to be measured by an electrical spectrum analyzer (ESA). The dual loops are combined in optical domain and only one PD is needed for the OEO, which simplifies the system structure and avoids the additional phase noise by other active devices.

When the gain of the circulation loops is larger than the loss, the oscillation modes fallen in the bandwidth of the SBS gain are built up. Only the oscillation mode with the frequency of being in phase both in the short loop and in the long loop can be constructed steadily due to the Vernier effect and the side-modes can be greatly suppressed [15,16].

As shown in the spectrum at point ③ in Fig. 2, the output frequency f_{osc} of the OEO is determined by the frequency deference between the frequency of signal laser and the one of pump laser with the relationship of [8]

$$f_{osc} = f_P - f_B - f_S \tag{1}$$

where f_B is the Brillouin frequency shift of the HNLF. From Eq. (1) it can be seen that the output frequency of the OEO can be tuned by changing the frequency of the signal laser or of the pump laser.

The Q value is a figure of merit influencing the phase noise of the OEO [1]. For the polarization multiplexed dual-loop OEO, the optical power distribution between the short loop and the long loop can be changed by adjusting polarization direction of unbalanced PM signal to the PBS. According to the Q value definition of the conventional OEO [1], the Q value of the polarization multiplexed dual-loop OEO can be expressed as

$$Q = \frac{2\pi f_{osc}\left(\tau_L{}^2 P_L + \tau_S{}^2 P_S\right)}{\rho(\omega)} \tag{2}$$

where τ_L, τ_S and P_L, P_s are the round-trip time and power in the long loop and short loop, respectively. $\rho(\omega)$ is the power density of the input noise. Eq. (2) can explain the Q value property of the polarization multiplexed dual-loop OEO with the power distribution between the two loops [16]. If much power is located in the long loop, the Q value will be large, say it is near to the Q value of single long loop OEO and the phase noise can be improved. For the polarization multiplexed dual-loop OEO, it is very flexible to distribute the power in the long loop and the short loop by changing the polarization state of unbalanced PM signal to the PBS, while the whole power in the two loops maintains a constant value without attenuation. It is the advantage compared with the coupler-based dual-loop OEO [13,15].

3. Experiment and results

An experiment based on the configuration shown in Fig. 1 is performed. A distributed feedback laser diode (DFB-LD, Emcore-1772, with a linewidth of 380 kHz) and a tunable laser (NKT, DK-3460, with a linewidth of 0.9 kHz) are used as the pump and signal lasers, respectively. The light wave from the DFB-LD is modulated

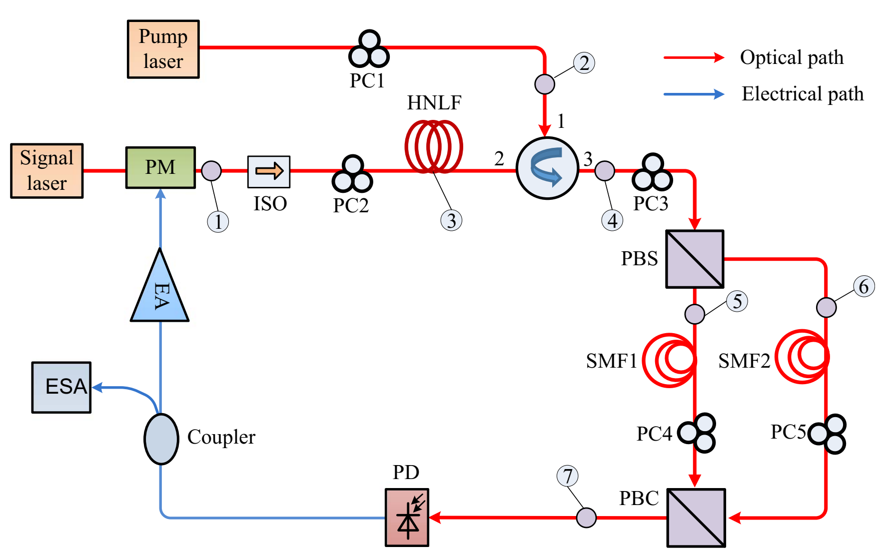

Fig. 1. Schematic of the polarization multiplexed dual-loop OEO based on SBS.