Microwave photonic filter with variable selectivity and shape by SBS and dispersion-induced phase mismatching

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Abstract- **We present a microwave photonic filter with variable selectivity and shape by using SBS and dispersion-induced phase mismatching in optical fiber. The selectivity and shape can be adjusted by tuning the pump power, polarization state and link dispersion.**

Keywords- fiber optics communications; stimulated Brillouin scattering; phase modulation

I. INTRODUCTION

Optical narrowband filter ranging from MHz to several GHz is an essential component in high-resolution optical signal processing, especially in the context of flexible switching in high speed optical transmission systems [1] and filtering in microwave photonics [2]. Filters with single passband response and high selectivity are highly desired for signal fidelity with low additional noise. Stimulated Brillouin scattering (SBS) as a primary non-linearity effecting, is a potential technology to implement narrow bandpass filter matching demands above. It has been proved that the SBS gain filter can be achieved by the amplitude or phase modulation method. Based on these modulation methods to detect the SBS response, suppress the generation of SBS by adjusting the phase to increase the SBS threshold has been demonstrated [3, 4]. Recently, we have demonstrated a SBS gain filter based on amplitude modulation method to achieve programmable microwave photonic filter [5]. Compared to the amplitude modulation method, phase modulation method can obtain a higher gain respond with lower pump power.

In this work, the SBS response is generated through high nonlinear fiber (HNLF) and detected by the amplitude- and phase-modulated detection signal. Through the interaction of the SBS's original gain and phase, both the SBS selectivity and the pump power efficiency can be enhanced greatly under phase-modulated detection method. By adjusting the wavelength of the laser near the zero-dispersion wavelength of the HNLF and introducing the time delay compensation (TDC) module, a SBS response with a selectivity of 26.08 dB can be obtained with only 2.28 dBm pump power. By further changing the polarization state and the TDC dispersion value, the corresponding selectivity and shape of the SBS can be adjusted through controlling SBS's original gain and phase respectively. It can be used to design SBS filter with high selectivity and various shapes.

II. PRINCIPLE

The SBS gain filter has been implemented by means of amplitude modulation (AM) detection under the single-frequency or multi-frequency pump. In this case, the SBS gain response is only related to the pump power, as shown in Fig. 1(a). Thus the higher SBS gain is, the higher pump power is. The selectivity of the SBS gain filter is limited because of the gain saturation. To improve the SBS selectivity and pump power efficiency, the phase modulation (PM) detection method is used to measure the SBS response. The probe signal has the equal amplitude and opposite phase condition after PM and is completely eliminated after photodetector (PD) detection. The corresponding signal response is generated only at the position where the matching of amplitude and phase is destructed by SBS's original gain and phase. So the corresponding SBS response depends not only on the pump power, but also on the phase introduced by the SBS's original gain, which can be seen in Fig. 1(b). Both the SBS selectivity and pump power efficiency can be improved extremely.

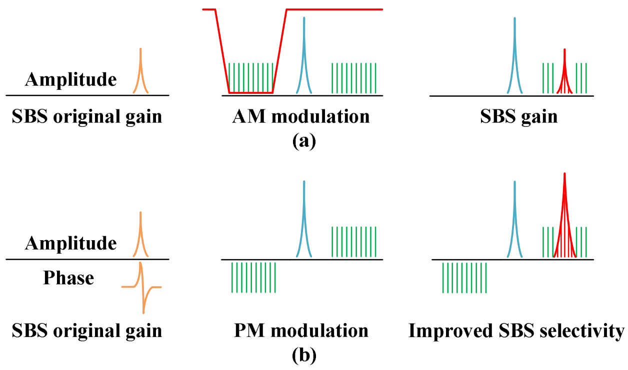

Fig. 1. Principle of (a) amplitude modulation (AM) detection and (b) phase modulation (PM) detection.

III. EXPERIMENT AND RESULTS

The experimental setup is shown as Fig. 2. A distributed feedback (DFB) laser is split into two branches by a 50:50

coupler to generate pump and probe signals in the upper and lower branch respectively. The upper branch is fed into an optical attenuator (ATT) and an erbium-doped fiber amplifier (EDFA) to adjust the pump power. A polarization controller (PC) is used to change the polarization state of SBS gain. In the lower branch, a sweeping signal with bandwidth ranging from 9 GHz to 11 GHz, which covers the SBS gain region, is produced by an electrical vector network analyzer (EVNA), then is modulated on the continuous wave (CW) light utilizing AM or PM as the probe signal. After an optical isolator (ISO) to prevent backscattered light, the probe light propagates in the 1km HNLF successively and is amplified once it is swept within the SBS gain region. The probe signal is then detected by a PD and sent into the EVNA. The amplitude and phase response is measured by the EVNA and the SBS response spectrum can be obtained by comparing the results between the SBS pump on and off.

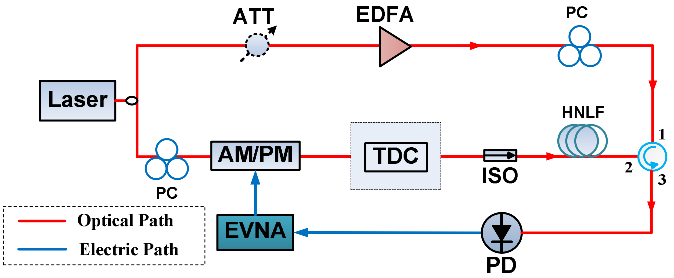

Fig. 2. Experimental setup for SBS selectivity measure.

Firstly, to compare SBS selectivity by different modulation detection method, the inherent gain and phase response of the SBS are detected by means of AM detection. The DFB is operating at 1538.27nm and the corresponding responses are shown in Fig. 3. In Fig. 3 (a), it can be seen that the SBS gain increases exponentially with the pump power, which is independent with phase. And the higher SBS gain causes the larger phase difference, as shown in Fig. 3(b). To achieve SBS selectivity of above 30 dB, the pump power needs to be above 15 dBm. So it is often required high power EDFA to amplify the pump, but large amplifier spontaneous emission (ASE) noise is introduced at the same time. Note that when the pump power is 15.43 dBm, the dents around the SBS gain are due to saturation of the PD, which can be solved by decreasing signal power into the PD's dynamic range through an ATT, as seen when the pump power is 20.42 dBm.

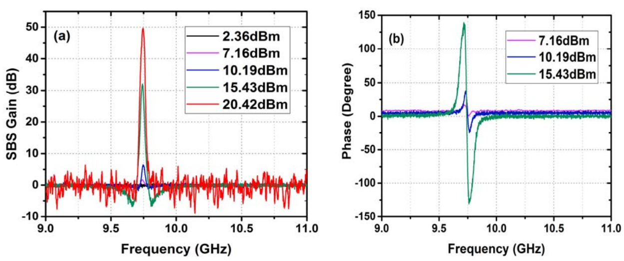

Fig. 3. SBS response of AM modulation detection (a) SBS gain response (b) SBS phase response.

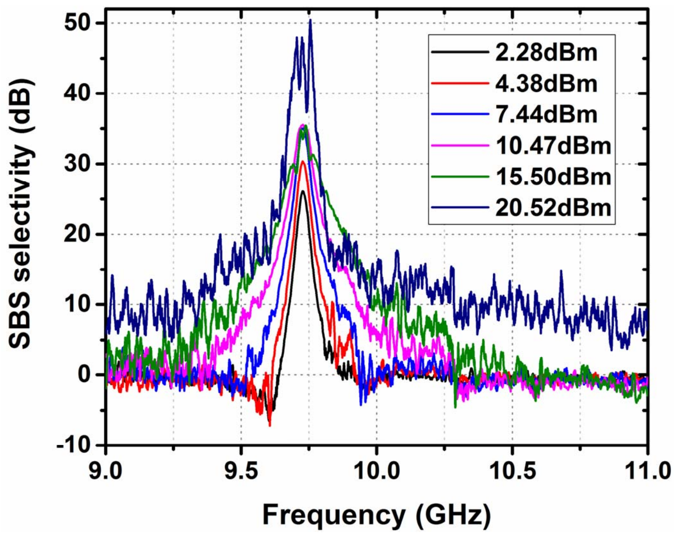

Fig. 4. SBS response of PM modulation with TDC.

In order to verify the enhancement of SBS selectivity and pump power efficiency, PM method is used in the next experiment. A PM is instead of the AM in above-mentioned experiment, and the DFB wavelength is set near the zero-dispersion wavelength of HNLF at 1540.27nm. A TDC is introduced to adjust the signal transmission dispersion, for the equal amplitude and opposite phase is necessary for perfect cancellation of unwanted band as shown in Fig. 2. The corresponding response is obtained by the reaction of original amplitude and phase of SBS at the same time, and the SBS selectivity is improved greatly, as shown in Fig. 4. The SBS selectivity of 26.08 dB is obtained under the only 2.28 dB pump power. The pump power of 7.44 dBm can achieve SBS selectivity of 35.01 dB, while the selectivity in the AM detection method is only 1.53dBm with the same pump power. But the SBS selectivity does not increase as the pump power increases infinitely due to the phase mismatch of adjacent frequency caused by the higher pump power, further the SBS selectivity is reduced. When the pump power is higher than 15.50 dBm, the SBS response has a multi-peak shape due to the double reactions of SBS's original gain and phase. The pump power is increased to 20.52 dBm, the high mismatch of the adjacent bandwidth also leading to large noise. To further increase the SBS selectivity and decrease noise, it is necessary to study the influence of SBS’s original gain and phase information on selectivity and shape. Note that this experiment give a relative increase in the SBS selectivity due to PM detection and not the absolute value of the SBS gain power.

The influences of SBS’s original gain on selectivity and shape responses are obtained by controlling the PC, as shown in Fig. 5. It is a practice to set the pump power to be around 15.50dBm, because around this value the SBS selectivity is relatively sensitive to SBS’s original gain. In Fig. 5, the response noise is minimum when SBS has the highest selectivity. And the multi-peak distribution of the SBS response can be adjusted by the polarization state, and even may appear a notch in the pass band, as shown in Fig. 5(c). Therefore, it’s a simple way to change the SBS selectivity and shape through controlling the polarization state.

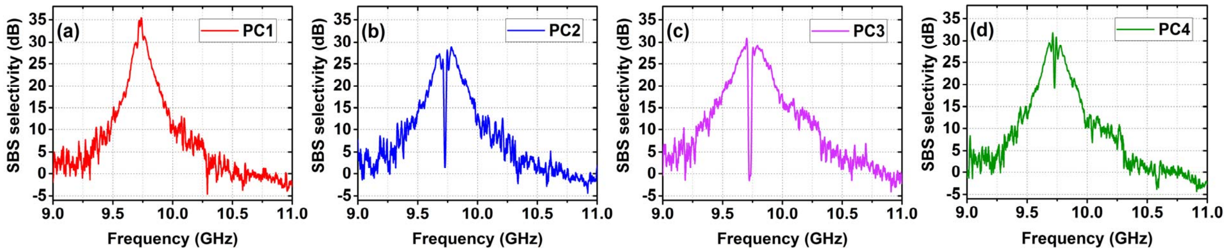

Fig. 5. SBS response with various polarization states.

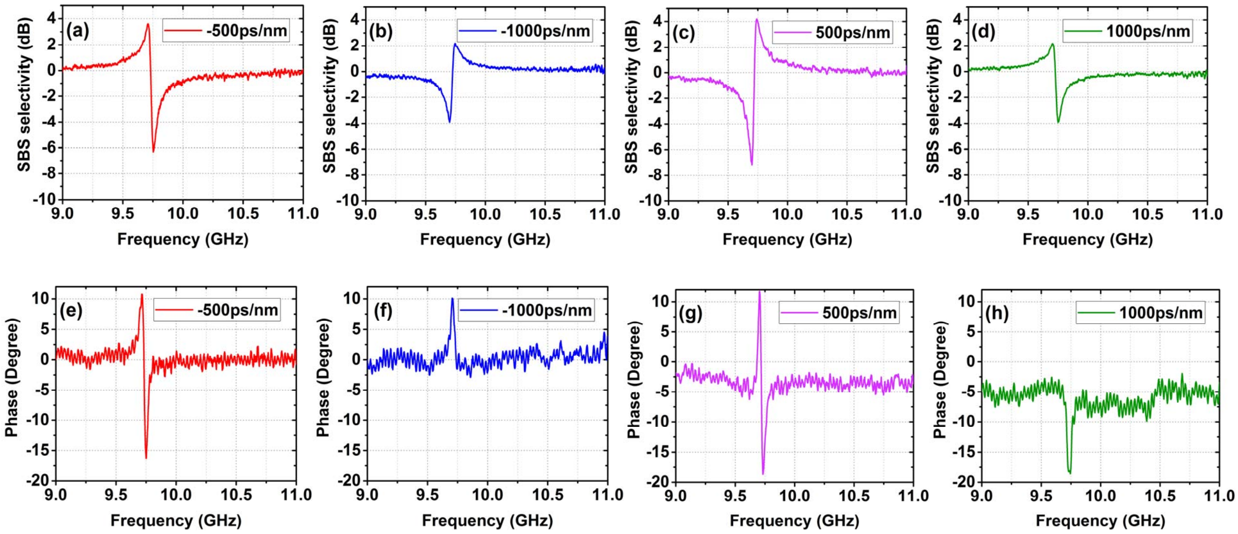

Fig. 6. SBS response with TDC desperation compensation of (a) -500ps/nm (b) -1000ps/nm (c) 500ps/nm (d) 1000ps/nm and their corresponding phase response (e)~(h).

For PM modulation method, phase information is also an important factor to influence SBS response. The pump power is set to be around 7.43 dBm, for around this value the SBS selectivity is insensitive to SBS's original gain. Note that in this part of the experiment, the influence of TDC on the phase response and shape of SBS is mainly considered, so the SBS polarization state is not changed during the experiment and the selectivity of SBS is not taken into account. By changing the dispersion compensation value of TDC, the detected SBS response can be obtained as shown in Fig. 6(a) ~ (d), and the corresponding periodic variation of SBS phase response is shown in the Fig. 6(e) ~ (h). It's experimentally demonstrated that the SBS phase response can be periodically changed corresponding to the dispersion compensation value introduced by TDC, so as the detected SBS's shape. This result provides a simple way to control the selectivity and shape of SBS response under single- or multi-frequency pump in the further experiment.

IV. Conclusion

We propose a high selectivity SBS filter through HNLF generation and PM detection method. The experimental results show that PM detection method can improve SBS's selectivity and pump efficiency greatly, compared to AM detection method. At the same time, controlling SBS's original gain and phase by changing the polarization state and the TDC dispersion value, a microwave photonic SBS filter with variable selectivity and shape can be achieved. It's a simple way to realize SBS filter with different shape under high selectivity.

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