TuC2.3 (Invited)
11.30 – 12.00

Nonlinear Fiber Based Processing for High Speed Optical Communication and Sensor Systems

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Abstract: We give a review of our recent research on nonlinear fiber based processing, including: multi-channel 80-GHz pulse train generation; suppression of polarization sensitivity in SBS sensor; and long distance sensing system based on Raman amplification.

1. Introduction

The fundamental nonlinear effects in fiber includes: (i) self-phase modulation (SPM), (ii) cross-phase modulation (XPM), (iii) four wave mixing (FWM); (iv) stimulated Raman scattering (SRS), and (v) stimulated Brillouin scattering (SBS). All these nonlinear effects can significantly degrade the performance of a wavelength-division-multiplexing (WDM) lightwave system [1]. One the other hand, fiber nonlinearities can also be beneficial: refractive-index effects (SPM, XPM, and FWM) have applications on pulse genration and all-optical signal processing; and stimulated scattering effects (SRS and SBS) can be used for signal amplification and sensing [2]. In this paper, we give a brief review of our recent research on nonlinear fiber based processing for high speed optical communication and sensor systems.

2. Multi-channel 80-GHz RZ pulse train generation based on FWM in highly nonlinear fiber

An invaluable element for high-speed optical communication systems is a return-to-zero (RZ) optical pulse train generator at the data clock speed or bit rate. Such a generator can be used as an optical clock, for optical sampling, or to imprint optical data bits. The most common method to generate high-speed pulse train is using a mode-locked laser, which is for a single channel and the tuning range of the wavelength is very limited. For WDM applications, it will require several expensive mode-locked lasers which are not affordable for real systems and most labs. Several methods have been reported on multi-channel pulse train generation based on FWM. A 10-GHz wavelength tunable RZ pulse source was generated based on FWM [3] and 14 channels 10-GHz short-pulse sources were obtained through XPM and FWM in a nonlinear optical loop mirror [4]. With the increase of bit rate, higher repetition rate of pulse train is required. We demonstrate simultaneous generation of 6-channel 80-GHz pulse trains in 1-km highly nonlinear fiber (HNLF) based on FWM [5]. As shown in Fig. 1, 3-channel C-band continuous-wave (CW) channels are amplified by the 80-GHz pulsed pump and become pulse trains and at the same time 3-channel pulse trains are generated at the converted L-band idler wavelengths. Fig. 2 shows the optical spectrum at output of the HNLF. It can be observed that both the signals and idlers are modulated by the pulsed pump to become 80-GHz pulse trains through the ultra-fast FWM effect. The waveforms of the generated optical pulses are measured by an auto-correlator. The pulse of each channel has nearly the same measured pulse width 3.7 ps.

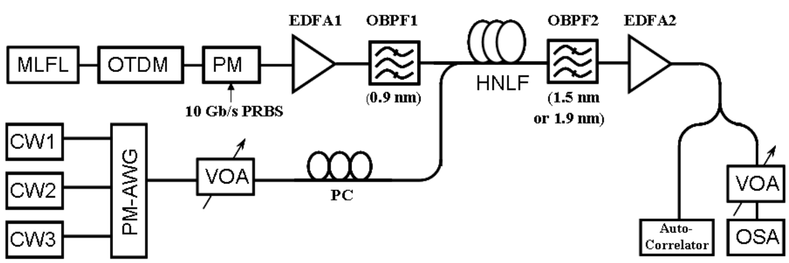

Fig. 1. Experiment setup of multi-channel 80-GHz RZ pulse train generation. MLFL: mode lock fiber laser. OTDM: optical time-division-multiplexing. PM: phase modulator. HNLF: highly nonlinear fiber. PM-AWG: polarization maintaining arrayed waveguide grating. PC: polarization controller. AC: auto-correlator.

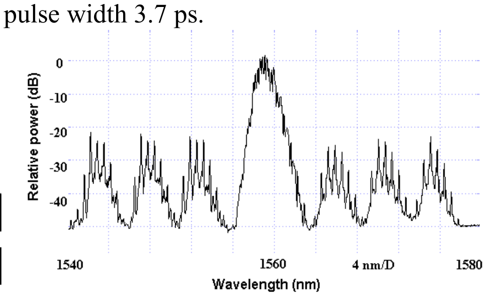

Fig. 2. Optical spectrum at output of the HNLF. Pump power is 26 dBm (the corresponding peak power is about 30 dBm). The input power of each CW light is -25 dBm.

3. Suppression of polarization sensitivity in optic distributed sensing system based on SBS

Optical fiber sensors are widely used as they are flexible, immune to electromagnetic interference, and applicable in many environments. The SBS based fiber sensor is capable of sensing temperature and strain over relative long distances by monitoring the changes of Brillouin frequency shift. However, since the SBS is a polarization sensitive process, the polarization sensitivity remains a key problem for SBS based fiber sensing system because it will induce the polarization noise and reduce the signal to noise ratio (SNR) of the sensor [6,7].

As shown in Fig. 3, we propose and demonstrate a novel method to suppress the polarization sensitivity in SBS based distributed sensing system [8]. In our scheme, the polarization diversity is introduced on the pulsed pump wave.

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A polarization beam splitter (PBS) splits the pump wave into two beams with orthogonal polarization states and one of the beams is delayed by a time related to the pulse width. After recombining of the two waves, the degree-of-polarization (DOP) decreases from 95% to only 5%. For temperature measurement, the polarization induced fluctuation is suppressed to ±3℃ from ±20℃; for strain measurement: it is suppressed from >±300 με to ±50 με.

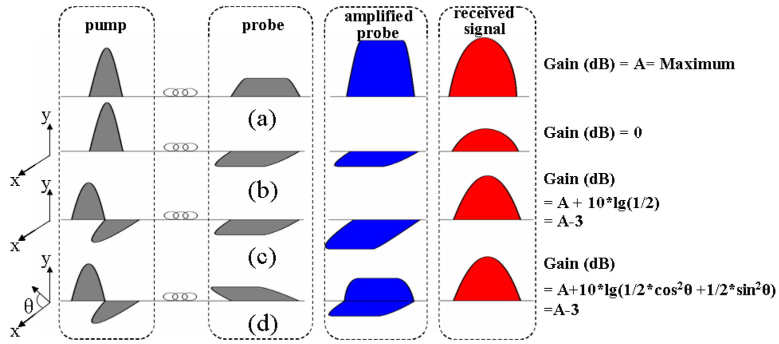

Fig.3. The fluctuations of Brillouin gain due to the relative polarization state between pump and probe waves. (a) The probe is parallel to the pump, without polarization diversity. (b) The probe is orthogonal to the pump, without polarization diversity. (c) The probe wave is orthogonal to one pump sub-pulse, with polarization diversity. (d) The probe wave is aligned at θ to one pump sub-pulse, with polarization diversity.

4. Long distance FBG sensor system based on EDF and Raman amplification

Fiber Bragg grating (FBG) fiber sensors have been considered to be the most popular approaches among a lot of sensing applications due to their high versatile advantages such as high sensitivity, compactness, high resolution for wavelength shift and high optical SNR. Due to the noise and loss induced by the Rayleigh scattering and attenuation along the fiber, the maximum transmission distance with a broadband light source is generally limited to 25km [9]. Because of that, the measurement distance of FBG fiber sensor system is a practical issue.

We demonstrate a novel 100-km FBG sensor system. As shown in Fig. 4, 100-km long distance FBG sensing is achieved by using only a Raman laser as pump at 1395nm and two segments of erbium-doped fiber (EDF) located at 50km and 75km, respectively. In this long distance FBG sensor system, no additional devices are needed along the fiber, except two segments of EDF which are spliced between the SMF at different location. Because the pump power of the EDF at 1480nm is generated along the fiber by the first order SRS, the pump power can be increased to a high level without lasing effect, which made the long distance measurement possible. Fig. 5 shows the reflected spectra of FBG of our 100-km long distance system at four different temperatures. We can see the optical SNR is beyond 30 dB.

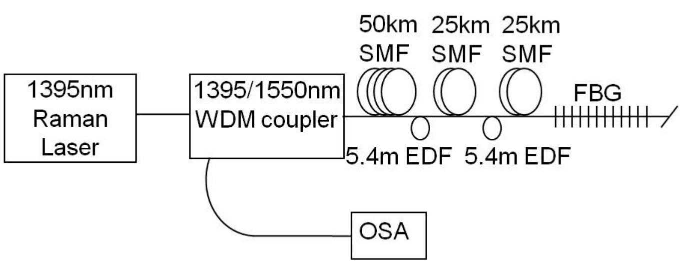

Fig. 4. Experiment setup of long distance FBG system based on EDF and Raman amplification.

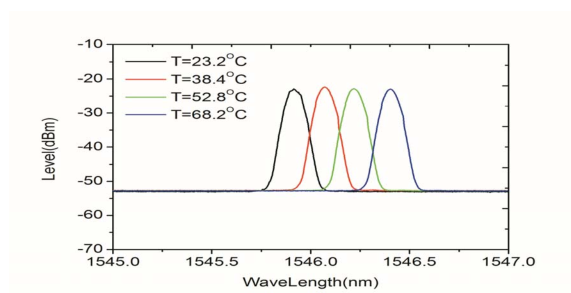

Fig. 5. The reflected spectra of FBG of 100-km long distance system at four different temperatures.

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