Polarization Independent Raman-Assisted Fiber Optical Parametric Amplifiers

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Abstract
We propose and demonstrate a polarization independent Raman-assisted fiber optical parametric amplifier using depolarized Raman and parametric pumps. The polarization dependent gain fluctuation has been reduced from >10 dB to less than 1 dB.

1 Introduction
Fiber optical parametric amplifier (FOPA) technology is a promising technology for future optical communication system [1]. Recently, Raman-assisted fiber optical parametric amplifier (RA-FOPA) is proposed to further increase the gain and gain bandwidth of the FOPA [2]. The Raman amplifier not only amplifies the signal power directly, but also indirectly amplifies the signal through amplifying the parametric pump [3]. However, an important issue that needs to be addressed is that both the gain of the Raman amplifier and FOPA are polarization dependent. As the state of polarization (SOP) of the signal in the transmission link is random in general, polarization independent operation of the Raman amplifier, FOPA, and RA-FOPA is highly desirable.

Polarization independent fiber Raman amplifiers (FRAs) and FOPAs have been achieved [4-5]. However, for polarization independent RA-FOPA, no such work has been reported. In depolarized FRA and FOPA schemes, two methods have been used to depolarize the parametric pump or the Raman pumps: polarization scrambling (PS) the pump light and orthogonally combining two linearly polarized pumps using a polarization beam combiner (PBC). In this paper, we demonstrate polarization independent RA-FOPAs using both depolarized Raman and parametric pumps.

2 Experimental Setup
Fig. 1 shows the experimental setup of the proposed polarization independent RA-FOPA. The parametric pump (tunable laser) is modulated by a phase modulator (PM) using a pseudo-random binary sequence (PRBS) at 2.5-Gbit/s in order to suppress the stimulate Brillouin scattering (SBS) effect. Then the parametric pump is depolarized by using two different schemes: one uses a commercial polarization scrambler (General Photonics PCD-104) to depolarize the parametric pump. By using the Agilent 8509 lightwave polarization analyser, the DOP of the output parametric pump after PS is measured to be 2%. The second scheme orthogonally combines two linearly polarized pump lights using a polarization beam combiner (PBC). In this scheme, as shown in Fig. 1, the pump beam is firstly split into two branches by a 3 dB optical coupler. A 70-meter long single mode fiber (SMF) is inserted in to one of the arms to destroy the coherence of lightwaves in two branches. A variable optical attenuator is used in another arm to equalize the output powers at two branches. By adjusting the polarization controllers (PCs), lightwaves from two optical branches are orthogonally combined by a PBC [23]. The DOP of output parametric pump PBC is measured to be 3.2%.

By using an erbium doped fiber amplifier (EDFA), the depolarized parametric pump is amplified to 500 mW and then passes a 0.8 nm tunable band-pass filter (BPF). After that, the parametric pump are coupled with input continuous wave (CW) signal using an 80:20 coupler and then launched into one piece of 1-km-long dispersion-flattened highly nonlinear fiber (HNLF) via circulator 1 (CIR1). The nonlinear coefficient, Raman gain coefficient, and attenuation at 1550 nm of this HNLF are 10.1 W⁻¹ km⁻¹, 4.6 W⁻¹ km⁻¹, and 0.9 dB/km, respectively. The injected powers of the parametric
pump and the signal coupled are set to 168 mW and 60 µW, respectively. In the other end of the fiber, a depolarized Raman pump is launched into the HNLF via CIR2 to provide polarization independent Raman gain. This Raman pump is depolarized by a PBC orthogonally combines two linearly polarized pump lights from two laser diodes (LD) operated at 1445 nm. The input powers of 1445 and 1455 nm Raman pumps are 328.5 mW and 352.5 mW, respectively.

3 Results and Discussion

Fig. 2(a)-(b) show the on-off gain spectra of RA-FOPA when the 1445 nm Raman amplifier is used and the parametric pump is set at 1539 nm (a), and 1545 nm (b) respectively. PD: polarization dependent; PI: polarization independent; PS: polarization scramble scheme; PBC polarization beam combination scheme.

In Fig. 2, we can notice that when Raman pump is absent, the gain behaviors of the depolarized schemes using PS and PBC are nearly the same. When depolarized Raman pump is added, we can observe about 6-dB gain enhancement at the parametric gain peak when compared with the case without Raman assistant. We also notice that up to 4 dB peak gain reduction has been observed in the polarization independent amplifiers. This is caused by the averaging effect in polarization independent RA-FOPA, which is consistent with results of other polarization independent schemes [4].

Fig. 3 shows the measured relative PDG difference when the polarization angle of input signal is varied. Here the parametric pump, the CW signal is set at 1545 nm and 1541 nm, respectively. And a 1455 nm Raman fiber laser is used for assistant. The relative PDG differences with and without polarization depolarization, with and without Raman assistant are all shown in Fig. 3. We can notice that the gain fluctuation due to the polarization dependence has been reduced from more than 10 dB to less than 1 dB by using our proposed polarization independent experimental setups.

4 Conclusion

In conclusion, a polarization independent RA-FOPA is experimentally demonstrated in this paper. Two different methods (PS and PBS) to depolarize the parametric amplifier are investigated, which have similar performance in this RA-FOPA. From the experimental results, the gain fluctuation due to the polarization dependent has been reduced from more than 10 dB to less than 1 dB.

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References