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Distributed Parametric Amplification at 1.3 μm in 25-km Single-Mode Fiber

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Abstract—Distributed parametric amplification (DPA) at 1.3-μm wavelength range is experimentally demonstrated, the first time to the best of our knowledge, in a spool of 25-km SMF. Multi-channel amplification is achieved with ~ 3-dB on-off gain.

Keywords—Distributed parametric amplifier (DPA); wavelength-division multiplexing (WDM); single-mode fiber (SMF);

I. INTRODUCTION

Distributed parametric amplification (DPA), one promising candidate for the distributed amplification of optical signal, has been studied in recent research [1]-[3]. Different from the discrete optical parametric amplifier (OPA) in the specially fabricated highly-nonlinear dispersion-shifted fiber (HNL-DSF) [4], [5], DPA adopts the widely available single-mode fiber (SMF) or dispersion-shifted fiber (DSF) in which the transmission and amplification of the optical signal can be achieved simultaneously. One of the most favorable merits of DPA lies in its capability of minimizing the signal power variation along the transmission span, which provides the best tradeoff between the noise figure and fiber nonlinearities [6]. With the help of DSF, DPA system with the configuration of both single pump [2] and two pumps [3] were recently demonstrated for WDM signals in the 1550-nm telecommunication window. However, as the most commonly used fiber type, SMF has not been demonstrated for DPA yet. One important reason is the zero-dispersion wavelength (ZDW) of the SMF, which locates at around 1.3 μm. Hence, the parametric pump should also be located in the same wavelength range. Previous study [7] has theoretically investigated the distributed amplification at 1.3-μm band. However, due to the lack of comparable amplification source as in the 1550-nm range, DPA at 1.3 μm has not been experimentally investigated yet. While in this paper, we demonstrated, the first time to the best of our knowledge, DPA at the 1.3-μm telecommunication window within a spool of 25-km SMF. Simultaneous amplification for up to three channels of WDM signals has been demonstrated, and a maximum on-off gain of 3 dB was achieved.

II. EXPERIMENTS

Fig. 1 illustrates the experimental setups for the proposed DPA system. As the first part of our experiment, the gain spectrum for 3 different pump wavelengths were measured, and the transmitter setup is as shown in Fig. 1(a). One tunable laser source (TLS) was adopted in the signal branch. While the pump, sourced from a DFB laser, was first phase modulated by a $2^{31}-1$ pseudorandom binary sequence (PRBS) at the phase modulator (PM). The purpose of phase dithering on the pump was to suppress the stimulated Brillouin scattering (SBS), which could limit the maximum pump power launched into the fiber. It is even more crucial for DPA, because the fiber length (tens of kilometers) is much longer than the lumped OPA (hundreds or even tens of meters). The pump power was then amplified to 17.5 dBm by a booster semiconductor optical amplifier (BOA). The optical band pass filter (OBPF) was used to reduce the amplified spontaneous emission (ASE) noise level from BOA. Polarization controllers (PC1-2) were used to minimize the insertion loss of both PM and BOA by aligning the corresponding state-of-polarization (SOP) with the transmission axis of each component. In order to protect the BOA and the TLS from any possible reflecting power, isolators (ISO1-2) were utilized accordingly.

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The pump and signal were then combined by a 95/5 coupler, and launched together into a 25-km SMF (Fig. 1(b), Corning® SMF-28™, attenuation: 0.35 dB/km @ 1310 nm, ZDW: \( \lambda_0 = \sim 1312 \) nm and nonlinear coefficient: \( \gamma = \sim 1.5 \text{ W}^{-1}\text{km}^{-1} \)). The SOPs of pump and signals were aligned by PC3 and 4 to attain the maximum gain during the parametric process.

During the second experimental part, the transmitter for WDM amplification is shown separately in Fig. 1(c). The input WDM channels were generated by three DFB lasers (DFB1-3), which were tuned by the temperature control module. The TLS was moved to the pump branch. The rest of the components were maintained the same as in the first part.

## III. RESULTS AND DISCUSSION

Fig. 2. Optical on-off gain spectra at the output of SMF with parametric pump at 3 different wavelengths: (a) 1311.9 nm, (b) 1312.5 nm and (c) 1313.1 nm.

Gain spectra for different pump wavelengths \( \lambda_p \) from 1311 nm to 1313 nm (\( \lambda_0 \pm 1 \) nm), were measured, and the results are shown in Fig. 2. Due to the low input pump power (< 15 dBm) available at the present stage, the maximum on-off gain value achieved was limited to 3 dB. Note that, as shown in Fig. 2, the relatively small gain bandwidth is due to the following reasons: (1) the pump power level, (2) the fiber length and (3) the ZDW fluctuation of the SMF. Nevertheless, these preliminary experimental results still verify DPA as a promising distributed amplification candidate for the 1.3-\( \mu \)m telecommunication window in SMF.

In order to further investigate our DPA performance, in the second part of the experiment, both 2-channel and 3-channel WDM signals amplification were demonstrated with single pump DPA, and their optical spectra at the SMF output with and without the pump are shown in Fig. 3 below. The pump power at the fiber input was 14.3 dBm, while the signals were kept below -18 dBm. For the 2-channel case (Fig. 3(a)), signals were located at 1310.93 and 1311.25 nm (0.32-nm spacing) and the pump was at 1311.8 nm. The corresponding on-off gains were 2.3 and 2.68 dB, respectively. In the 3-channel case, signals were located at 1310.79, 1311.06, and 1311.32 nm (0.26-nm spacing), while the pump wavelength was kept the same, nearly 2-dB on-off gain were achieved for all WDM channels (Fig. 3(b)).

Fig. 3. Optical spectra at the output of SMF with and without pump: (a) 2 channels; (b) 3 channels (OSA resolution bandwidth: 0.06 nm).

## IV. CONCLUSIONS

We have demonstrated, for the first time to the best of our knowledge, DPA at 1.3-\( \mu \)m band in a spool of 25-km SMF. The gain spectra for different pump wavelengths around ZDW of SMF were measured, and the amplification of multi-channel signals was achieved with a maximum on-off gain of ~ 3-dB.
REFERENCES


