Demonstration of polarization pulling in a fiber-optical parametric amplifier

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Abstract: We report the experimental demonstration of all-optical polarization pulling of an initially polarization-scrambled signal using a fiber-optical parametric amplifier. Nonlinear polarization pulling has been achieved for both the signal and idler with 25 dB gain.

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In the past few years, several authors have reported all-optical polarization attraction of light using nonlinear optical effects in fibers [1-4]. This so-called nonlinear polarization pulling (NPP) appears as a promising solution for photonic-based applications requiring high-precision polarization control and thus opens up a new mean to fully control the state of polarization (SOP). So far, NPP has been demonstrated using counterpropagating pump waves [1-2], stimulated Raman scattering (SRS) [3] and Brillouin scattering (SBS) [4].

In this work, we report the experimental demonstration of nonlinear polarization pulling of an initially polarization-scrambled signal in a fiber-optical parametric amplifier (FOPA) [5]. NPP has been achieved for both the signal and idler waves over a broad bandwidth using the strong polarization-dependent gain (PDG) of parametric amplifier [5]. Figure 1 shows the experimental setup of the fiber-optic parametric polarizer. Two linearly-polarized continuous-wave (cw) external cavity tunable lasers (at λ_s and λ_p), are used as signal and pump sources, respectively. The pump laser was spectrally broadened with a $LiNbO_3$-based phase modulator (PM) driven by a 2^{23}–1 pseudorandom bit sequence at a fundamental frequency of 3 GHz in order to suppress SBS while keeping a constant cw power. Using a high-resolution optical spectrum analyzer (OSA), we measured the so broadened pump linewidth to be $\Delta\nu_P \cong 3$ GHz. The output was then launched into a high-power Erbium-doped fiber amplifier (EDFA, 33 dBm) to reach enough power to provide parametric gain. A band-pass filter centered at λ_P permitted us to reduce the ASE noise level well below the pump level and keep the optical signal-to-noise ratio (OSNR) high at the input of the FOPA. The pump was then coupled with the signal into the fiber using a 99/1 tap fiber coupler. For the parametric amplifier, we used a highly nonlinear fiber (HNLF) having a length of 490 m, a nonlinear coefficient $\gamma = 11.2\ W^{-1}km^{-1}$, a zero-dispersion wavelength (ZDW) of 1553.1 nm, a loss factor α=0.54 dB/km, and a polarization mode dispersion (PMD) of 0.07 $ps.km^{-1/2}$, respectively. Note that the PMD would not affect the NPP efficiency but only the output SOPs of the copropagating pump and signal waves. To demonstrate NPP, the input signal SOP was polarization-scrambled using a commercially available polarization scrambler and the output SOP was analyzed on the Poincaré sphere by means of a polarimeter. A tunable filter is placed before the analyzer to reject most of the pump power. Output spectra were simultaneously recorded using an optical spectrum analyzer (OSA) with 1 nm resolution in order to monitor the parametric gain. The pump wavelength was set to λ_p=1556 nm to provide broadband parametric gain in the small anomalous group-velocity dispersion (GVD) regime and the signal wavelength at λ_s=1546 nm matches the maximum gain level on the anti-Stokes sideband. Before testing the NPP efficiency, we first performed a measurement of the polarization-dependent gain by comparing a signal SOP parallel and orthogonal to the pump.

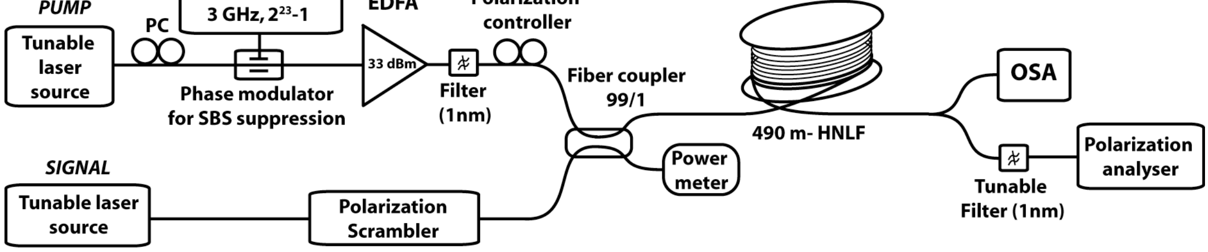

Fig 1. Experimental arrangement of the fiber-optical parametric polarizer. EDFA : Erbium-doped fiber amplifier. OSA :Optical spectrum analyser. PRBS : pseudorandom bit sequence. PC : Polarization controller.

For an input pump power of 29.5 dBm, we measured an on/off parallel gain of 25 dB and a perpendicular one of 6 dB, leading to a high PDG of about 20 dB. Then, the signal was polarization-scrambled at the FOPA input. Figures 2 show the experimental output signal and idler SOPs on the Poincaré sphere for increasing pump power. The corresponding gain spectra are also depicted in the bottom of Fig 2. The Poincaré sphere represents the three normalized Stokes parameters in unit radius. The input signal power was set to -21 dBm. As it can be clearly seen, the degree of polarization of the signal significantly increases with the parametric gain and the best degree of polarization is obtained for a parametric gain of 25 dB in the nondepleted pump regime while keeping an OSNR of 22 dB. The output signal power was measured at -3 dBm. Interestingly, the idler SOP is also pulled to the pump SOP with a better efficiency than the signal. This is due to the fact that the idler wave is generated with a SOP that matches with the pump only due to the strict scalar phase-matching conditions. We further checked that the parametric amplified spontaneous emission (ASE) is also polarized with a very good degree of SOP by turning off the signal power. This is a unique property of FOPA that has already been observed through noise figure measurements [6].

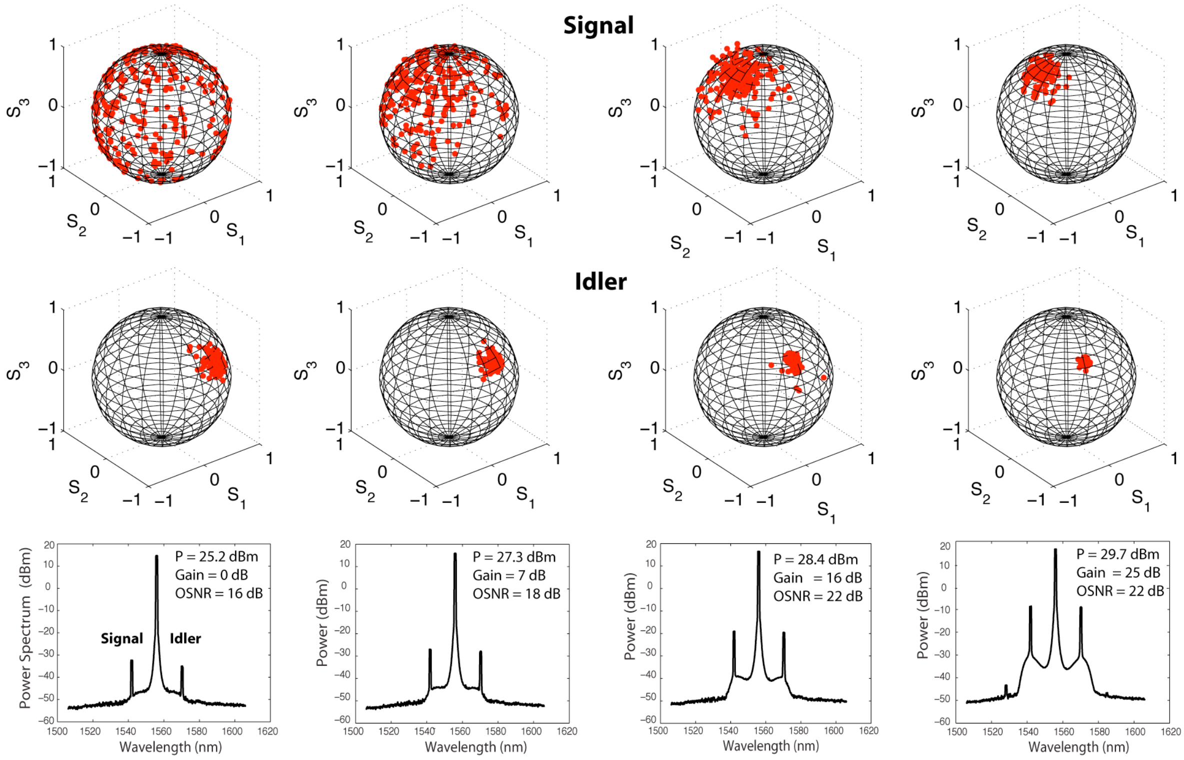

Fig. 2. Output state of polarization (SOP) of the signal (top) and idler (middle) waves measured by a polarimeter and visualized on the Poincaré sphere of unit radius, while input signal SOP is scrambled and pump power increases from 25.2 dBm to 29.7 dBm. Bottom: corresponding output gain spectra. The input pump power is indicated in insets together with the on/off gain and the signal OSNR.

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