Polarization-Insensitive Widely Tunable Wavelength Conversion Based on Four-Wave Mixing Using Dispersion-Flattened High-Nonlinearity Photonic Crystal Fiber with Residual Birefringence

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Abstract *We demonstrate a simple polarization-insensitive scheme in a FWM-based wavelength converter using only a short span of high-nonlinearity dispersion-flattened PCF with residual birefringence with over 32 nm of tuning and 0.9-dB polarization sensitivity.*

Introduction

In a wavelength-routed optical network, wavelength conversion [1] plays an important role in reducing wavelength blocking and providing more flexibility in network management. In particular, all-optical wavelength conversion based on four-wave-mixing (FWM) in fiber is a promising technique due to its ultrafast response and transparency to both bit-rate and modulation format. However, FWM in fibers strongly depends on the relative state of polarization (SOP) of the signal to the pump (i.e. >20dB), which is a major obstacle to applying it in real system where the incoming signal polarization is random. Several polarization-insensitive schemes have been reported, such as polarization-diversity loop [2], non-degenerate FWM using two orthogonal pumps with different wavelengths [3], etc. In this paper, we realize the polarization-insensitive operation with a simple straight-line configuration using only a short span of dispersion-flattened high-nonlinearity photonic crystal fiber (PCF) with residual birefringence. The polarization dependence is reduced to less than 0.9 dB and a wide wavelength tuning range of 32 nm is achieved.

Principle of Operation

Fig. 1 shows the operation principle of the polarization-insensitive scheme. The PCF we used in the experiment exhibits the residual birefringence with 5-ps delay between the fast and slow axes. When the combined light enters into the PCF, both signal and pump will be split into two orthogonal polarization components with a corresponding amplitude ratio given by the input SOP. Thus, two independent FWM will occur in the PCF along both fast and slow axes of PCF simultaneously. By adjusting the input polarization of the pump to make it 45° to the principal axis of the fiber, the two orthogonally polarized components of the pump will have equal amplitude. Consequently, The converted signals on both axes will have the same conversion efficiencies (defined as the ratio of the converted signal power to the input signal power), so the sum of them will become constant regardless of the SOP of the input signal. In principle, a span of PMF should be added after the PCF to compensate the birefringence induced by the PCF on the converted signal. However, in 10 Gb/s experiments, the delay caused by this birefringence (5 ps) is only 1/20 of the bit period (100 ps) so it has negligible impact on the converted signal. Thus, the compensation procedure is omitted, further simplifying the whole configuration.

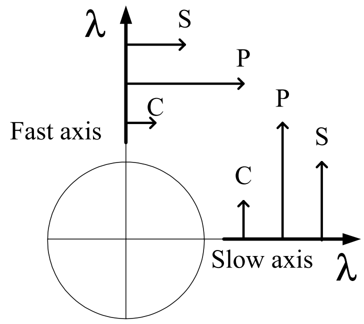

Fig. 1 Schematic operation principle. The circle shows the cross section of PCF with birefringence; S, P and C represent the signal, pump and converted signal respectively

Experiment

Fig. 2 shows the experimental setup for 10 Gb/s operation. The input signal is 2^{31}-1 10 Gb/s NRZ PRBS generated by one DFB-LD followed by an external Mach-Zehnder intensity modulator. This input signal is combined with a wavelength-tunable CW pump laser using a 3-dB coupler. The combined signal is launched into a high power EDFA with the total output power of 800 mW. The power of the pump is about 3 dB higher than the power of the signal. The amplified light is then injected into a segment of 41-m PCF provided by Crystal Fiber [4]. It has a dispersion around -1 ps/km/nm over 1500-1600 nm with a nonlinear coefficient of 11.2 $(W{\cdot}km)^{-1}$. The dispersion slope is less than $1{\times}10^{-3}$ ps/km/nm^2. The attenuation of the fiber is below 10 dB/km in the 1550-nm range. Both ends are spliced to SMF and the total loss of the 41-m PCF is 2.4 dB. Moreover, this fiber exhibits a residual birefringence on the order of 10^{-5}-10^{-4} during fabrication. Our measurement shows that there is about 5-ps delay between the fast and slow axes. By adjusting the PC before the pump laser, the input polarization of the pump is 45° to the principal axis of the fiber, thus realizing the polarization-insensitive operation. Finally, the converted signal is filtered out using an optical band-pass filter (OBPF) with 1-nm 3-dB bandwidth.

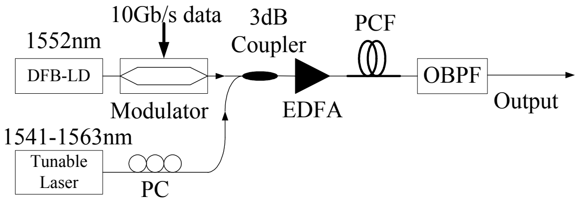

Fig. 2 Experimental setup

Results and Discussions

At first, the signal wavelength (S) is fixed at 1552 nm and the CW pump wavelength (P) is tuned to 1546 nm. The up-converted signal (C) appears at 1540 nm. The spectrum obtained after PCF is shown in Fig. 3. The OSNR of the converted signal is 30 dB, and the conversion efficiency is about -15 dB. To demonstrate the polarization-independent operation of the wavelength converter, Fig. 4 plots the relative converted signal power against different input signal polarization state. The power variation of the output is less than 0.9 dB. Fig. 5 (a) and (b) show the obtained eye diagrams (after preamplifier before photodetector) corresponding to the largest and smallest output power, respectively. Clear eye diagrams are shown in both cases, and no modulation instability induced amplitude noise is observed due to the normal dispersion of the PCF over the 1550-nm range. It also indicates that the residual birefringence of the PCF did not cause significant distortion to the signals.

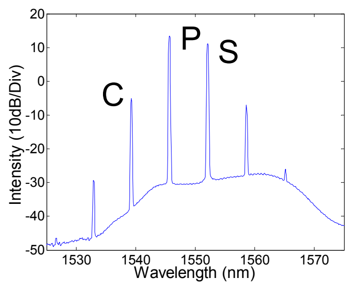

Fig. 3 Output spectrum of 12-nm up-conversion

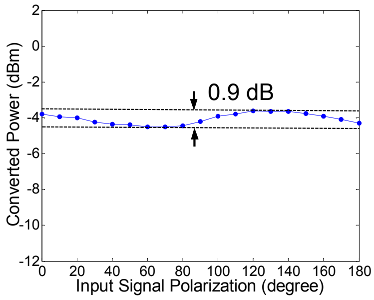

Fig. 4 Converted signal power vs. the input signal polarization

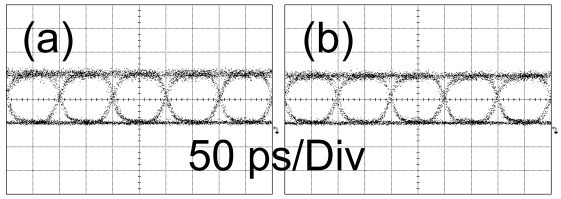

Fig. 5 Eye diagrams (after preamplifier before the photodetector) corresponding to (a) the largest and (b) the smallest output power when the input signal polarization is changed (as shown in Fig. 4)

The relationship between the conversion efficiency and the converted output wavelength is shown in Fig. 6. In this measurement, we fix the signal wavelength and tune the pump wavelength (from 1541 nm to 1563 nm with 1-nm spacing) to obtain different outputs. A 3-dB tuning range of 32 nm is achieved where the peak conversion efficiency is -15 dB.

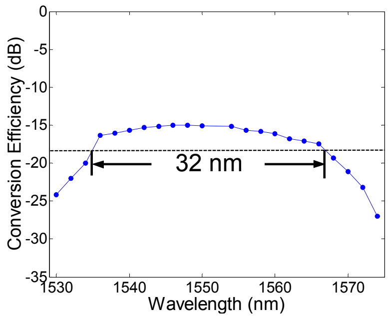

Fig. 6 Output conversion efficiency vs. the converted wavelength

When this scheme is applied in a higher bit-rate wavelength conversion, such as 40 Gb/s or above, the birefringence-induced delay will be significant with respect to the bit period, thus compensation of the birefringence may become necessary. Further reducing the birefringence might be a solution. However, too small birefringence might reduce the polarization-insensitivity. So, optimization of this birefringence value for higher bit-rate system requires further investigation.

Conclusions

Utilizing the residual birefringence of nonlinear PCF, we achieve the polarization-insensitive wavelength converter in a simple straight-line configuration with less than 0.9-dB polarization sensitivity. A wide wavelength tuning range of 32 nm is realized due to the dispersion-flattened property of this PCF. The results show that such wavelength converters are promising for wide-band wavelength conversion applications in future all-optical networks.

References

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