Demonstration of Polarization Insensitive Wavelength Conversion of 112-Gb/s Polarization Multiplexed RZ-QPSK Signals Using Bismuth-Oxide-based Nonlinear Optical Fiber with High SBS Threshold

Ming-Fang Huang[1,2], Jianjun Yu[1], and Gee-Kung Chang[2]

1. *NEC Laboratories America, Princeton, NJ 08540, USA, email: mhuang@nec-labs.com*
2. *School of Electrical & Computer Engineering, Georgia Institute of Technology, GA 30332, USA*

Abstract: Polarization insensitive wavelength conversion by employing a dual pump scheme in 112-Gb/s polarization-multiplexed RZ-QPSK system has been realized by using a 2-m Bismuth-Oxide-based nonlinear optical fiber (Bi-NLF) with high SBS threshold.

OCIS codes: (060.2330) Fiber Optics Communications; (060.4250) Networks.

1. Introduction

Future high throughput networks require super broad transmission systems due to the increasing demand of upcoming multi-gigabit wired and wireless video and data access services. Wavelength-division multiplexing (WDM) provides a cost-effective and efficient use of the available bandwidth in fiber communication systems. All-optical wavelength conversion (WC) is one of the key technologies to enhance the flexibility of future WDM networks such as reconfigurability, nonblocking capability and wavelength reuse [1-4]. Polarization multiplexing technique has been used to increase the capacity of the transmission system, therefore, polarization insensitive WC of the polarization multiplexing signal is becoming a hot research topic [1-3, 5]. Several methods for all-optical WC had been proposed based on self-phase modulation (SPM), cross-phase modulation (XPM), and cross-gain modulation (XGM) [6-8]. Among these WC technologies, four-wave mixing (FWM) is one of the most promising schemes to achieve wavelength conversion, because it is fully transparent to the signal bit rate and modulation format [9, 10]. In this application, silica-based high nonlinear fiber (HNLF) has been widely used due to its high efficiencies [11], even though high input power is required to improve the efficiency of nonlinear process. Nevertheless, the maximum pump power is limited by stimulated Brillouin scattering (SBS), due to the lower SBS threshold of the HNLF. Consequently, bismuth-oxide-based nonlinear fiber (Bi-NLF) is a desirable device for efficient signal processing due to its high SBS threshold and ultra nonlinearity [10, 12].

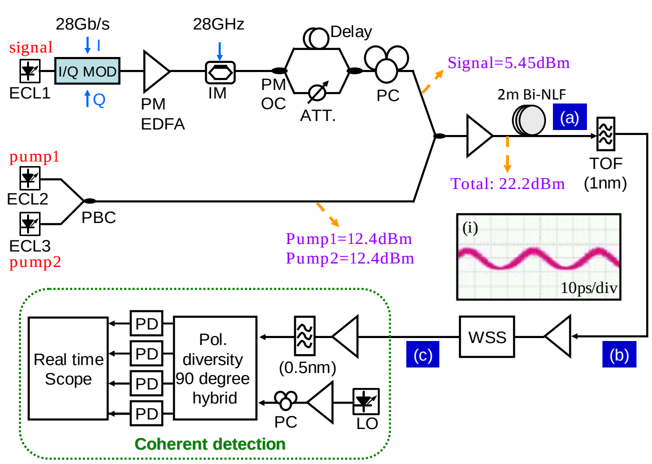

Fig. 1: Experimental setup of wavelength conversion for PolMux-RZ-QPSK signal. ECL: external cavity laser. MOD: modulator. IM: intensity modulator. PMOC: polarization maintained optical coupler. ATT.: attenuator. PBC: polarization beam combiner. TOF: tunable optical filter. WSS: wavelength selected switch. LO: local oscillator. PC: polarization controller. PD: photodetector.

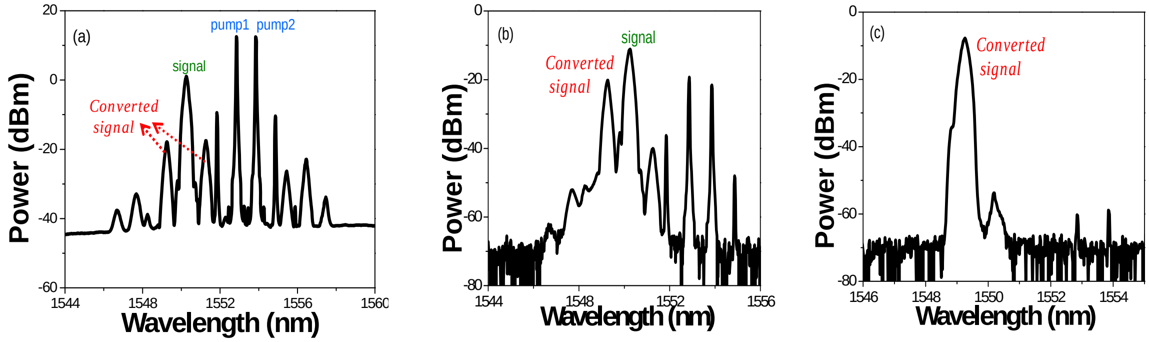

Fig. 2: Received optical spectrum (0.1-nm resolution) at the corresponding points in Fig.1. (a)-(c): After WC, 1-nm TOF and WSS.

Furthermore, Bi-NLF fiber provides the opportunity to implement a range of optical signal processing devices with only a few meters of fiber length. With digital coherent detection, polarization multiplexing return-to-zero quadriphase shift keying (PolMux-RZ-QPSK) has been reported as a modulation format due to its high spectral efficiency as well its tolerance toward chromatic dispersion (CD) and polarization mode dispersion (PMD) [2]. In this paper, we experimentally demonstrated high-speed 112Gb/s signal polarization insensitive wavelength conversion based on FWM in 2-m Bi-NLF using PolMux-RZ-QPSK modulation format and digital coherent detection. To our knowledge, this is the first time that polarization insensitive wavelength conversion for 100Gb/s PolMux-RZ-QPSK signals has been demonstrated using digital coherent detection and Bi-NLF.

2. Experimental configuration and results

The experimental configuration is displayed in Fig. 2. Three tunable external cavity lasers (ECL) with line-width smaller than 100 kHz are utilized, two of them (ECL2, ECL3) are coupled by a polarization beam combiner (PBC) and used for the pumping (pump1, pump2) at 1552.84 and 1553.84 nm with 12.4 dBm for each. Therefore, the polarization direction of pump1 and pump2 is always orthogonal. The other signal at 1550.26 nm with 5.45-dBm power is employed in the 112-Gb/s PolMux-RZ-QPSK transmitter with polarization multiplexer. The PolMux-RZ-QPSK transmitter consists of a dual-parallel Mach-Zehnder modulator (I/Q MOD), an intensity modulator (IM), a polarization- maintaining EDFA (PM-EDFA), and a polarization-multiplexing unit. The I/Q MOD is biased at the null point with 2.1 V of half-wave electrical voltage and driven by a 28-Gb/s data stream. The 28-Gb/s data is obtained by time-multiplexing four 7-Gb/s PRBS signals (each with pattern length of 2^{11}-1). Note that the two 28-Gb/s data signals are de-correlated by introducing different bit delays with respect to each other (the resulted pattern length of the 28Gig baud signal is 2^{13}-4). To introduce RZ-pulse shaping, a common IM which is driven by 28-GHz clock to crave out ~40% duty cycle is added after the PM-EDFA. The waveform of the 100 Gb/s signal is inset (i) in Fig. 1. Before Bi-NLF, one EDFA is utilized to boost the power to get 11 dBm of signal and 18 dBm of each pumping. After 2-m Bi-NLF, with total loss of 5.2 dB, nonlinear coefficient of 1050 W^{-1}/km, and dispersion of -250 ps/nm/km at 1550 nm, one tunable optical filter (TOF) with bandwidth of 1 nm and a 25-GHz wavelength selected switch (WSS) is used to select the converted signal to the receiver. Fig. 2 (a)-(b) shows the received optical spectrum with 0.1-nm resolution after WC, 1-nm TOF and 25-GHz WSS which measured at the points (a)-(c) in Fig. 1, respectively. At the receiver, polarization-and phase-diverse coherent detection uses a polarization-diversity 90-degree hybrid, a tunable ECL local oscillator (LO) and four single-ended photo detectors (PD). The sampling and digitization (A/D) function is achieved by using a 4-channel Tektronix digital storage scope (DSA72004) with 50Gs/s sample rate and 12 GHz electrical bandwidth. The captured data is then post-processed using a desktop PC. For this experiment, errors were counted over 20×60,000 symbols (20 data sets, each data sets consists of 60,000 symbols) so that the average BER for PolMux-RZ-QPSK signal is based on 4.8 $\times 10^{6}$ bits.

3. Experimental results

Fig. 3 shows the measured BER of 100-Gb/s PolMux-RZ-QPSK as a function of received optical signal-to-noise ration (OSNR) with 0.1-nm reference bandwidth before and after wavelength conversion. From this figure, it can be seen that the required OSNR at BER equals to 10^{-3} is 16 dB after WC. There is a 1.1-dB OSNR penalty caused by WC within 2-m Bi-NLF. The constellation diagrams of x-axis and y-axis for

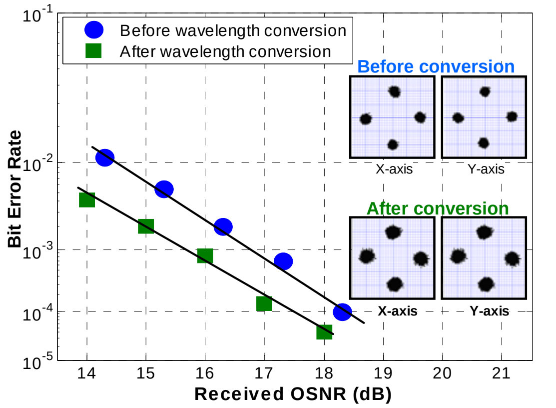

Fig. 3: Measured BER as a function of optical OSNR (0.1-nm reference bandwidth) of 112-Gb/s PolMux-RZ-QPSK signals before and after WC. The constellationis before (40-dB OSNR) and after (25 dB OSNR) WC are inserted.

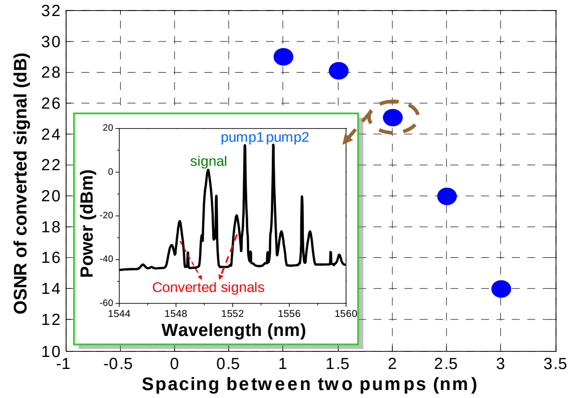

Fig. 4: Measured OSNR of converted signal as a function of wavelength spacing between two pumps

the signal before and after conversion are inserted in Fig. 3. Due to the OSNR of the converted signal is smaller than that of the original signal, therefore, the constellation diagram after conversion is worse. In order to study the conversion efficiency in this scheme, the OSNR as a function of frequency spacing between two pumps is exhibited in Fig. 4. The OSNR decreased from 28 to 14 dB while the spacing detuned from 1 to 3 nm. The optical spectrum is inset in Fig. 4 for 2-nm detuned wavelength spacing. As far wavelength separated, as weak OSNR of converted signal obtained because of the large mismatched phase in the Bi-NLF.

4. Conclusion

By using dual pump scheme, we have successfully demonstrated wavelength conversion based on FWM using a 2-m Bi-NLF fiber for 112-Gb/s PolMux-RZ-QPSK systems employing digital coherent detection. The required OSNR after wavelength conversion is about 16 dB at $BER=10^{-3}$. The conversion efficiency in this proposed scheme was obtained by tuning and analyzing the wavelength spacing between two pumps. The observed OSNR of the converted signal is decreased from 28 to 14 dB while the frequency spacing is detuned from 1 to 3 nm. To our best knowledge, this is the first time that wavelength conversion of polarization multiplexed 100-Gb/s signal has been realized based on polarization insensitive dual-pump FWM and by using 2 m of Bi-NLF with coherent detection and digital signal procession. Furthermore, the shorter length of the nonlinear fiber required in this scheme can significantly reduce the size of the nonlinear-optical-signal-processing devices.

5. References

[1] J. Yu and M. F. Huang, “Polarization insensitive wavelength conversion techniques for 100Gb/s polarization-diversity signal,” in *Proc. OECC*’09, pp. 1–2.
[2] J. Yu, and M. Huang, “Wavelength Conversion for 112Gbit/s PolMux-RZ-QPSK Signals Based on Four-Wave Mixing in High-Nonlinear Fiber Using Digital Coherent Detection”, ECOC 2008, Mo.3.C.5.
[3] J. Ma et al., “Wavelength conversion based on four-wave mixing in high-nonlinear dispersion shifted fiber using a dual-pump configuration”, IEEE JLT, vol. 24, pp. 2851–2858, 2006.
[4] M. Takahashi et al., “FWM Wavelength Conversion with Over 60nm of 0dB Conversion Bandwidth by SBS-Suppressed HNLF,” in *Proc. OFC*’09, paper OWU1.
[5] M. F. Huang and J. Yu, “Polarization Insensitive Wavelength Conversion for 4×112Gbit/s Polarization Multiplexing RZ-QPSK Signals,” Optics Express, Vol. 16, No. 26, pp. 21161–21169, 2008.
[6] Y. Liu et al., “Error-free 320 Gb/s SOA-based Wavelength Conversion using Optical Filtering”, in *Proc. OFC*, 2006, pp. 1–3.
[7] J. Yu et al., “All-optical wavelength conversion of short pulses and NRZ signals based on a nonlinear optical loop mirror”, IEEE JLT, Vol. 18, pp. 1007–1017, 2000.
[8] W. Wang et al., “Raman-enhanced regenerative ultrafast all-optical fiber XPM wavelength converter”, IEEE, JLT, Vol. 23, pp. 1105–1115, 2005.
[9] N. Sugimoto et al., “Bi-based fibers for amplifiers and nonlinear applications,” in *Proc. LEOS*’06, paper WC1.1.
[10] J. H. Lee et al., “Bismuth-Oxide-Based Nonlinear Fiber With a High SBS Threshold and Its Application to Four-Wave-Mixing Wavelength Conversion Using a Pure Continuous-Wave Pump,” IEEE JLT, Vol. 24, pp.22–29, 2006.
[11] M. Takahashi et al., “Low-Loss and Low-Dispersion-Slope Highly Nonlinear Fibers,” IEEE JLT, Vol. 23, pp. 3615–3624, 2005.
[12] N. Sugimoto, T. Nagashima, T. Hasegawa, S. Ohara, “Bismuth-based optical fiber with nonlinear coefficient of 1360 $W^{-1}km^{-1}$,” in *Proc. OFC*’05, paper PDP26.