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Abstract. A simple method for phase stabilization of ultrashort optical pulse train is presented. By using cross-polarization effect in high nonlinear photonic crystal fiber, optical pulses from a mode-locked fiber laser are wavelength converted with stable phase character. A differential phase shift keying modulation system is successfully built to test the performance of this method. [DOI: 10.1117/1.OE.51.4.040508]

Subject terms: optical communications; phase modulation; phase stabilization.

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1 Introduction

Ultrashort optical pulse sources play very important roles in high-speed optical fiber communication systems. They can be used as sources in high-speed optical time division multiplexing (OTDM) systems and samples in all-optical sampling orthogonal frequency multiplexing (AOS-OFDM) systems.[1,2] With complex modulation formats used, such as differential phase shift keying (DPSK) and differential quaternary phase shift keying (DQPSK), higher requests on not only pulse width but also phase stability are demanded than amplitude-modulated systems. Nowadays, mode-locked laser-diode (MLLD) and mode-locked fiber laser (MLFL) are two main sources to generate such optical pulses.[3,4] Among them, MLFL is a promising technique for low pulse jitter and high output power. Many techniques have been proposed to remove amplitude variation caused by the supermode noise.[5] However, the phase coherence between pulses is more important for detection of the differential phase modulated signals. Semiconductor optical amplifier (SOA) based wavelength conversion has been introduced to eliminate phase fluctuation between optical pulses in a DPSK system.[6] Due to the limit of recovery time in SOA, such method can only work in pulse duration larger than 10 ps. In higher bit rate OTDM system, a 40 GHz MLFL with an etalon installed in the cavity was been used, which greatly improves the stability in the optical phase.[7]

In this letter, a novel method for ultrashort optical pulse stabilization has been proposed by employing cross-polarization modulation (CPM) effect in high nonlinear photonic crystal fiber (HNPCF). The phase character of pulses after wavelength conversion is mainly determined by the peak power of pump pulses and has nothing to do with the phase noise of the pump pulses. A DQPSK modulation system is set up to test the performance of the proposed method. The results show that the eyediagrams of phase stable pulses are much better than the original ones.

2 Principle and Experiment

The cross-polarization effect in high nonlinear fiber is mainly based on cross-phase modulation. When the pump and probe are linear polarized with 45-deg difference of input fiber angle, the output polarization of probe can be controlled by the pump intensity. And by using a polarizer, the probe is wavelength converted. The probe transmittivity T_p can be expressed by:[8]

$$T_p = \frac{1}{4}|1 - \exp(i\Delta\phi)|^2 = \sin^2\left(\frac{\Delta\phi}{2}\right).$$

When the phase difference ($\Delta\phi$) for the probe align with two orthogonal axes is equal to odd multiple of π, it becomes 100% transmission. $\Delta\phi$ is

$$\begin{aligned}\Delta\phi &= \frac{2\pi}{\lambda}(n_x - n_y)L = \Delta\phi_L + \Delta\phi_{NL}\\ &= \frac{2\pi L}{\lambda}[\Delta n_L + 2n_2(1-b)|E_p|^2],\end{aligned}$$

where n_x and n_y are refraction index of x- and y-axis, Δn_L and n_2 are linear birefringence index and nonlinear index respectively, $b = 1/3$, and E_p is the input pump light. It can be seen that $\Delta\phi$ is only determined by the amplitude of the pump and avoids the pump phase variation. Thus, the wavelength converted probe pulse will have better phase coherence than the pump.

In order to test the system performance, a DQPSK experimental is set up as shown in Fig. 1. A 10 GHz ultrashort optical pulse whose pulse width is 2 ps train from a commercial MLFL passes through the wavelength converter (WC) to overcome the poor pulse-to-pulse coherence. Figure 2(a) shows the spectrum of the pump light from the MLFL with central frequency of 193.5 THz. By using polarization controllers (PCs), the polarization direction of the pump pulse is maintained along the slow axis of HNPCF and that of the probe light is 45 deg to the slow axis. The pump light and the 192.6 THz probe light couple into the

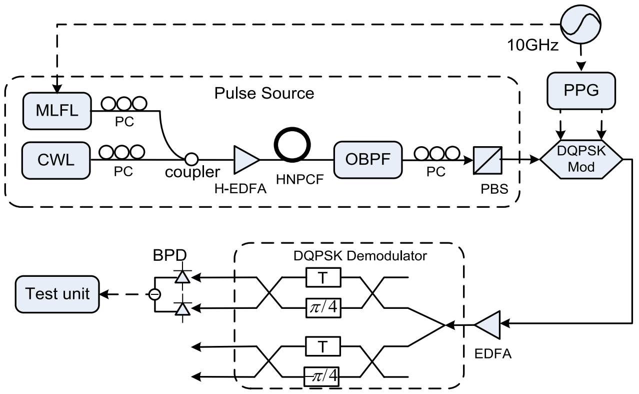

Fig. 1 Experimental setup.

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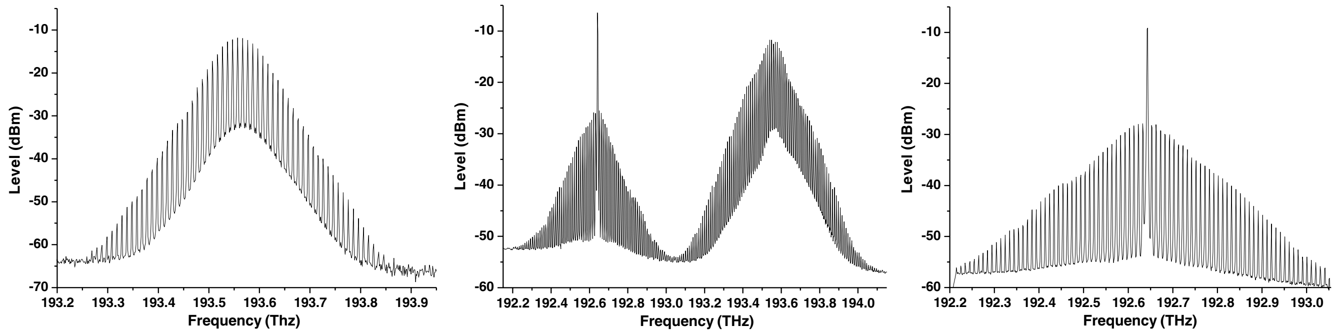
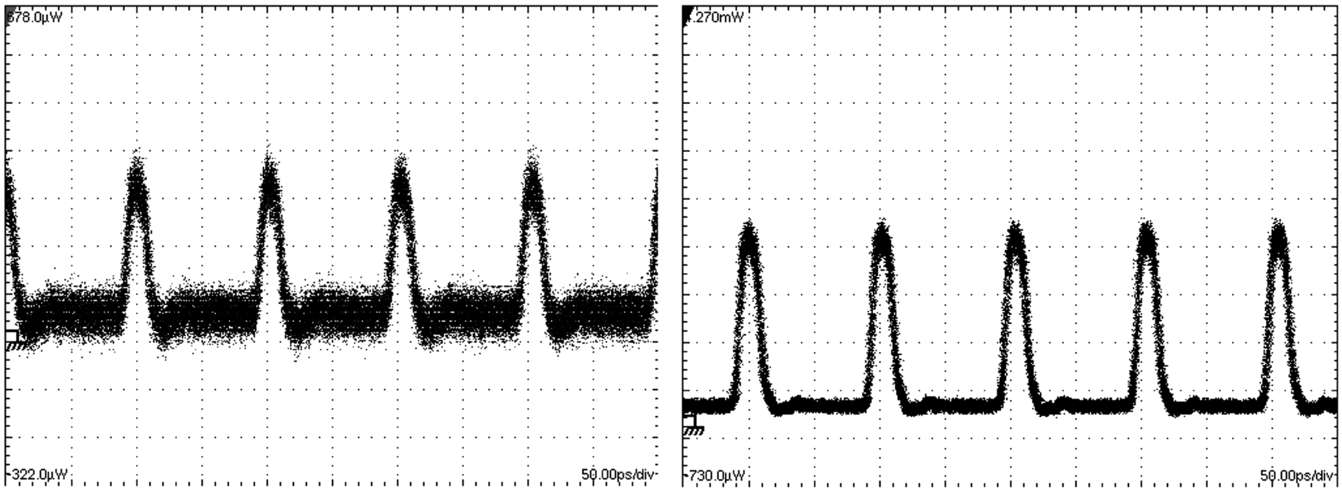


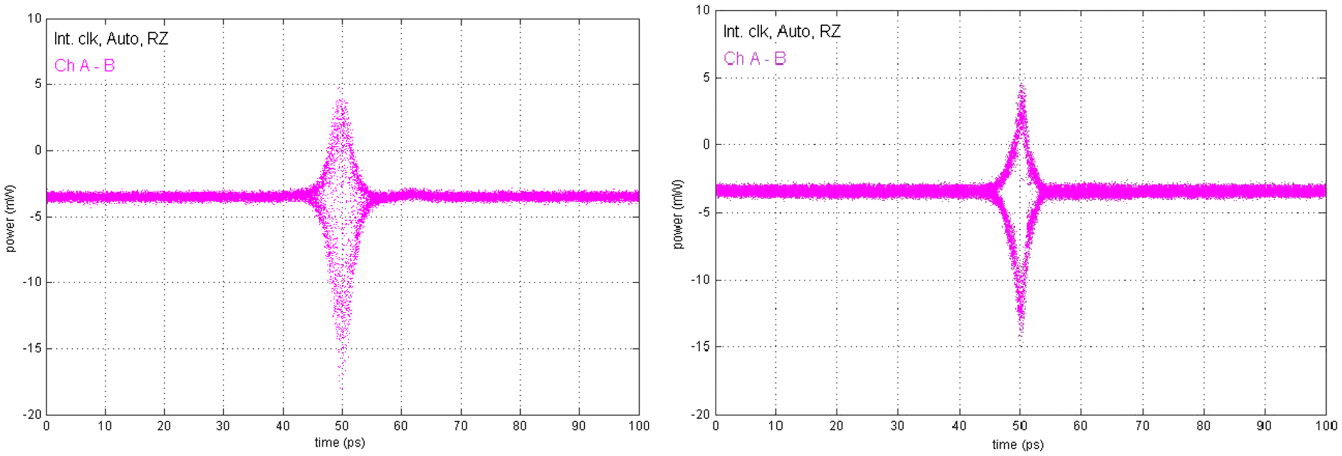
(a) (b) (c)

Fig. 2 Spectra of (a) pump pulse, (b) combined pump and probe after HNPCF, and (c) probe pulse after wavelength conversion.



(a) (b)

Fig. 3 Pulse profiles of (a) pump, and (b) probe after wavelength conversion.



(a) (b)

Fig. 4 Eyediagrams with (a) MLFL, and (b) pulses after wavelength conversion.

HNPCF to complete CPM effect after being amplified by an erbium-doped fiber amplifier (EDFA) with 25 dBm output power. The power of pump and probe before EDFA is set to 3 and 0 dBm respectively. The HNPCF has a high nonlinear coefficient of 12 W^{-1}/km and 50 meter length. The spectrum after the CPM effect in HNPCF is shown in Fig. 2(b), including the probe and pump light. The output of HNPCF passes through an optical band-pass filter (OBPF) by adjusting its central frequency to avoid disturbance from the pump pulse. The filtered signal is adjusted by a PC and split by a polarization beam splitter (PBS) to extract an optical pulse train whose spectrum is shown in Fig. 2(c). The original pump pulse profile is shown in Fig. 3(a), while Fig. 3(b) shows the pulse after wavelength converted. For the CPM effect is dominated by the peak power of the pump pulses, the optical pulse after WC is independent of the pump pulse phase noise and has good coherent characteristics for DQPSK modulation.

3 Results

We test the DQPSK modulation and demodulation by using two optical sources, the MLFL and the one after wavelength converted. The received eyediagrams are tested by a 500 GHz optical sampling oscillascope (EXFO PSO-100). Figure 4(a) shows the eyediagram of the MLFL used. It can be seen that there are lots of noise samples, which means it is not suitable for practical systems. Whereas the eyediagram shown in Fig. 4(b) with the source after WC has clear opening, which implies good phase coherence between pulses.

4 Conclusion

A novel method for ultrashort optical pulse phase stabilization based on CPM is proposed. The output pulse train of a MLFL is wavelength converted to eliminate phase variation. The results of a DQPSK system show that with this method, the pulse-to-pulse coherence can be highly increased. So this method can be used in future ultra-high-speed optical communication systems.

Acknowledgments

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References

1. H. Weber et al., "Ultrahigh-speed OTDM-transmission technology," *J. Lightw. Technol.* **24**(12), 4616–4627 (2006).
2. H. Chen, M. Chen, and S. Xie, "All-optical sampling orthogonal frequency-division multiplexing scheme for high-speed transmission system," *J. Lightw. Technol.* **27**(21), 4848–4854 (2009).
3. S. Arahira et al., "Transformlimited optical short-pulse generation at high rate over 40 GHz from a monolithic passive mode-locked DBR laser diode," *IEEE Photon. Technol. Lett.* **5**(12), 1362–1365 (1993).
4. E. Yoshida, N. Shimizu, and M. Nakazawa, "A 40-GHz 0.9 ps regeneratively mode-locked fiber laser with a tuning range of 1530-1560 nmA 40-GHz 0.9 ps regeneratively mode-locked fiber laser with a tuning range of 1530-1560 nm," *IEEE Photon. Technol. Lett.* **11**(12), 1587–1589 (1999).
5. G. T. Harvey and L. F. Mollenauer, "Harmonically mode-locked fiber ring laser with an internal Fabry–Perot stabilizer for soliton transmission," *Opt. Lett.* **18**(2), 107–109 (1993).
6. K. Chan et al., "Mitigation of pattern-induced degradation in SOA-based all-optical OTDM demultiplexers by using RZ-DPSK modulation format," *IEEE Photon. Technol. Lett.* **15**(9), 1264–1266 (2003).
7. M. Yoshida, K. Kasai, and M. Nakazawa, "Mode-hop-free, optical frequency tunable 40-GHz mode-locked fiber laser," *IEEE J. Quantum Electron.* **43**(8), 704–708 (2007).
8. G. Agrawal, *Nonlinear Fiber Optics*, Elsevier Science & Technology, San Diego, CA (2006).