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Generation of optical pulses with tunable pulsewidth using 1.9 meter bismuth-based highly nonlinear fiber

K. K. Qureshi, H. Y. Tam and W. H. Chung
Photonics Research Center and Department of Electrical Engineering
The Hong Kong Polytechnic University, Hong Kong, China
Tel: +852-2766-6190, Fax: +852-2330-1544, Email: qureshi.ee@polyu.edu.hk

P. K. A. Wai
Photonics Research Center and Department of Electronic and Information Engineering
The Hong Kong Polytechnic University, Hong Kong, China
Tel: +852-2766-6231, Fax: +852-2362-8439, Email: enwai@polyu.edu.hk

N. Sugimoto
Asahi Glass Co., Ltd, 1150 Hazawa-cho, Yokohama 221-8755, Japan

Abstract: We demonstrate a simple method to generate optical pulse train with tunable pulsewidth at 10 Gb/s using four-wave mixing in 1.9 m bismuth based highly nonlinear fiber.

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1. Introduction

Optical sources capable of generating pulses with tunable pulsewidth are useful to applications such as high speed optical communication, optical sampling, and all-optical signal processing. In high speed transmission, return-to-zero format is better than non-return-to-zero format because the former can be used in phase shift keying technique which can provide higher immunity against fiber impairments [1,2]. Chernikov, et.al. [3] demonstrated duration tunable pulse generation using an electro-absorption modulator. Recently pulse width tunable optical pulse generation using four-wave mixing (FWM) has been reported using 1 km of highly nonlinear fiber [4] as well as 20 m of photonic crystal fiber (PCF) [5]. In this paper we demonstrate generation of optical pulses with tunable pulsewidth based on four wave mixing (FWM) effect in only 1.9 meter of bismuth-based highly nonlinear fiber (Bi-HNLF) courtesy of Asahi Glass Co., Ltd. When two pulse trains at different wavelengths with fixed pulsewidth are launched into the Bi-HNLF, pulse trains at new wavelengths are generated through FWM effect in the nonlinear medium. The pulsewidths of the pulses in the newly generated pulse trains depend on the extent of the temporal overlap between the two pump pulses trains. By tuning the relative delay between the two pump pulse trains, the pulsewidth of generated pulse trains can be continuously tuned.

2. Experimental Results

Figure 1 shows the schematic of the experimental setup we used to demonstrate the generation of duration tunable optical pulses using bismuth-based highly nonlinear fiber. The two pump pulse trains are generated by external modulation of two tunable lasers (TL-1& TL-2) using LiNbO_{3} electro-optical modulators. The wavelengths of two lasers are set at 1553.33 nm (λ_{1}) and 1554.10 nm (λ_{2}) respectively. The two modulators are driven by two pulse pattern generators (PPGs) which are synchronized. The delay between the two pulse trains is controlled by an optical delay line (ODL) placed after one of the modulators (MOD-2) as shown in Fig. 1. A polarization controller placed after the other modulator (MOD-1) is used to optimize the conversion efficiency of the FWM process inside the Bi-HNLF by aligning the states-of-polarization of the two pulse trains. The two pulse trains are then combined using a 3-dB coupler and are amplified to a peak power of ~25 dBm by using an erbium doped fiber amplifier (EDFA) with a maximum saturation output power of 27 dBm. The combined signals are then launched into Bi-HNLF. In order to reduce splicing losses, the two ends of the Bi-HNLF are first connected to two segments of ultra high numerical aperture (NA) silica fiber (UHNA4, Nufern) which has a mode field diameter (MFD) of 4 µm. The two high NA fibers are then connected to conventional silica fiber (SMF28) which has a MFD of 10.4 µm. The total loss at the input side of the Bi-HNLF, which includes the splice loss between the SMF28 and UHNA4, the splice loss between the UHNA4 and the Bi-HNLF, and the propagation losses in the SMF28 and the UHNA4, is 1.1 dB. The total loss at the output side of the Bi-HNLF is 2.6 dB. The propagation loss of the Bi-HNLF is 2.0 dB/m at 1550 nm. The total loss of the Bi-HNLF is therefore 7.5 dB. The refractive index of the core and cladding are 2.22 and 2.13 respectively. Thus the numerical aperture of this fiber is ~100 times larger than that of the conventional silica based highly nonlinear dispersion shifted fiber. Although the Bi-HNLF has a large normal GVD coefficient, which is mainly due to the material dispersion of the high refractive index glass, its effect however is not significant because of short fiber length used. The Bi-HNLF has a relatively high stimulated Brillouin scattering (SBS) threshold compared to that of silica-based HNLF and hence SBS suppression schemes are not required [6]. Figure 2 shows the output spectra of FWM signals at 10 Gb/s measured after the Bi-HNLF. We observed that the two pump pulse trains generated new pulse trains at new wavelengths through the four wave mixing process. The inset shows the spectrum of one the generated pulse train at 1554.92 nm (λ_{4}). The optical peak power at this wavelength is around 0 dBm. Finally, a thin film filter with a 3-dB bandwidth of 0.6 nm is used to separate the newly generated pulse train at λ_{4}. The filtered output is sent to an optical spectrum analyzer with 0.01 nm resolution and a 50 GHz sampling oscilloscope with a 40 GHz photo-detector. The pulsewidth of the generated pulse at λ_{4} depends on the extent of the temporal
overlap between the pump pulses which can be varied with the optical delay line. Figure 3 shows the pulsewidth versus the optical delay at 5 Gb/s (triangles) and 10 Gb/s (circles). We found that the output pulsewidth varies approximately linearly with the relative delay between the pump pulses. The maximum pulsewidth occurs when the two pump pulse trains are synchronized. The tunable range of pulsewidth at 5 Gb/s is from 86 to 18.5 ps while that at 10 Gb/s is from 36 to 19 ps. The minimum pulse width is limited by the rise and fall times of the electrical RF clock and the electrooptic modulators. Figure 4 show the temporal pulse shapes of the generated pulse train at 10 Gb/s for FWHM of 38.4, 29.8, and 19 ps. Figure 5, shows the temporal pulse shape of the generated pulse at 5 Gb/s for FWHM of 56, 30, and 18.5 ps respectively.

3. Summary
In summary, we have demonstrated generation of optical pulses with tunable pulsewidth at 5 Gb/s and 10 Gb/s based on four-wave mixing in only 1.9 m of bismuth-based highly nonlinear fiber. By optically tuning the delay between the two pump pulse trains, the pulsewidth of the generated pulse train is continuously tuned. We showed that the full-width-half-maximum of a 5 Gb/s pulse train can be continuously tuned from 86 ps to 18.5 ps and that of a 10 Gb/s pulse train can be continuously tuned from 36 ps to 19 ps.

4. References

Fig. 1. Experimental setup for the generation of optical pulses with tunable pulsewidth. (Inset shows a microscopic view of Bi-HNLF). TL: tunable laser; PC: polarization controller; MOD: modulator; EDFA: erbium doped fiber amplifier; BPF: bandpass filter; ODL: optical delay line.

Fig. 2. Spectra at the output of Bi$_2$O$_3$-HNLF. (Inset shows the spectrum of a pulse train at 10 Gb/s with a pulsewidth of 29.8 ps).

Fig. 3. Pulsewidth versus the delay at 5 Gb/s (triangles) and 10 Gb/s (circles).

Fig. 4. Timing diagrams for pulsewidth tunable optical pulse generation at 10 Gbit/s.

Fig. 5. Timing diagrams for pulsewidth tunable optical pulse generation at 5 Gbit/s.