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Silicon Waveguide Based 320 Gbit/s Optical Sampling

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Abstract: A silicon waveguide-based ultra-fast optical sampling system is successfully demonstrated using a free-running fiber laser with a carbon nanotube-based mode-locker as the sampling source. A clear eye-diagram of a 320 Gbit/s data signal is obtained.

OCIS codes: (190.4360) Nonlinear optics, devices, (190.7110) Ultrafast nonlinear optics

1. Introduction

With the realization of ultra high speed optical communication systems, it is often required to measure the optical waveforms with picoseconds or even smaller resolution. Therefore, all-optical waveform sampling techniques are developed to overcome the electronic bandwidth limitation. Nonlinear effects for optical sampling gates are key elements in all-optical sampling systems. The use of highly nonlinear fiber (HNLF) as a four-wave mixing (FWM) based sampling gate has been demonstrated to have good performance [1]. Recently, silicon has attracted more and more research interest because of its potential for integration on well-developed electronic platforms. Optical signal processing using the nonlinear FWM process in a silicon waveguide has been demonstrated in e.g. [2]. Compared to HNLF, a silicon waveguide has a much higher nonlinear coefficient and a clear potential for monolithic integration. In this paper, we will demonstrate an ultra-fast all-optical waveform sampling system based on FWM in a silicon waveguide. This is demonstrated in the successful sampling of a 320 Gbit/s data signal.

2. Silicon waveguide based optical sampling system

Fig. 1 shows the silicon waveguide based optical sampling system scheme. Free running sampling pulses and the data signal are sent into the silicon waveguide. Polarization controllers are used to adjust the polarization states of sampling pulses and the data signal into the silicon waveguide in order to align the signals to one of the main axis of the silicon waveguide. In the waveguide the asynchronous optical sampling is performed by FWM between the data signal and the sampling pulses. After the waveguide a band pass filter is used to select the FWM product which will be amplified and detected on an oscilloscope. The sampling pulse train is also used to synchronise the data acquisition of the oscilloscope to the optical sampling.

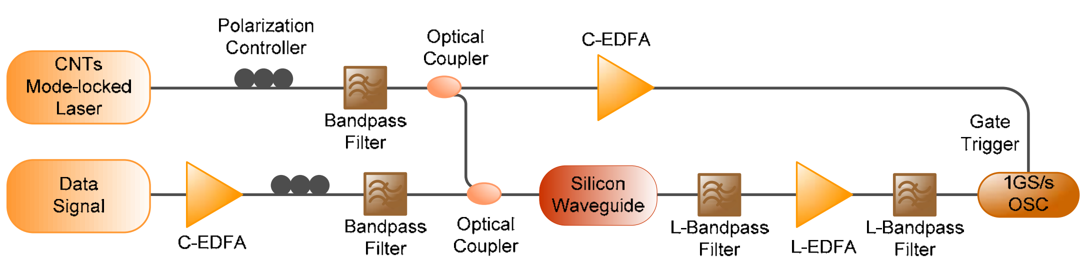

Fig.1. Silicon waveguide based all-optical sampling system scheme.

The sampling source is a free running passively mode-locked erbium fiber laser which uses carbon nanotubes (CNTs) as the mode-locker [3]. The repetition rate of the generated pulse train is ~18MHz. The sampling pulses are about 700 fs FWHM sech^2 pulses and with central wavelength at 1558 nm. The silicon waveguide used in the optical sampling system is 5 mm long and its cross section dimensions are 300 nm × 450 nm (see Fig. 2 (Left)). Nano-taper couplers [4] are used at both ends of the waveguide to increase fiber-to-chip coupling efficiency. The insertion loss for the waveguide is about 7.5 dB, which includes 2 dB propagation loss and 5.5 dB coupling loss. The measured conversion efficiency is -3 dB with -2 dBm average power of the sampling pulses going into the silicon waveguide. In the conversion efficiency measurement, a continuous wave (CW) light at 1540nm is used as the probe signal. Fig. 2 (Right) shows the optical spectrum of the CW probe, sampling pulses and FWM product after the silicon waveguide. The conversion efficiency is determined by integrating the FWM spectrum compared to the CW probe and incorporating the sampling pulses duty cycle (~ 45 dB).

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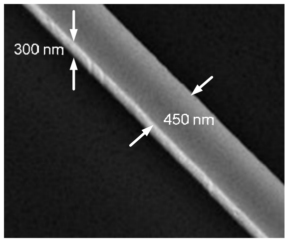


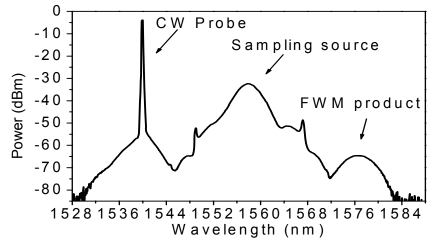
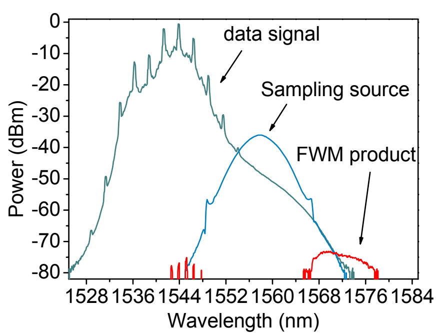


Fig. 2 (Left) Scanning electron micrograph picture of the silicon wave guide. (Right) Optical spectrum after silicon waveguide.

3. Demonstration of sampling a 320 Gb/s RZ data signal

The silicon waveguide based all-optical sampling system is used to monitor a 320 Gbit/s Optical Time Division Multiplexing (OTDM) RZ modulated data signal. An erbium glass oscillator (ERGO) optical pulse source generates a 10 GHz pulse train tuned at 1542 nm which is data modulated with a 2^7-1 PRBS. Then the 10 Gbit/s data pulses are multiplexed to 320 Gbit/s by a passive fiber delay PRBS and polarization maintaining multiplexer (MUX). The 320 Gbit/s data signal is amplified using an EDFA. Band pass filters are inserted after the sampling source and data signal respectively to suppress the ASE noise. The average power into the waveguide of the sampling source and the data signal are - 4 dBm and 18 dBm respectively. Fig. 3 (Left) shows the FWM product at 1574 nm after optical filtering to suppress the data signal and the sampling pulses. The FWM product is detected by a 100 MHz photodetector and sent into a 1GS/s oscilloscope after filtering and amplification in an L-band EDFA. Fig. 3 (Right) shows the clear eye-diagram which is obtained when sampling the 320 Gbit/s OTDM data signal. Some variation is seen between the amplitude of the sampled data pulses. This is due to suboptimal multiplexing of the data signal and not an artefact from the sampling system. Despite the clear eye diagrams seen in Fig. 3 (Right), there is a significant offset in the sampling result which means the '0' level is not at 0. This relatively high offset comes from the L- band EDFA which is used to amplify the FWM product to a level where the signal can be detected. The FWM effect in the silicon waveguide can be enhanced by increasing the input average power of the sampling source or the data signal. In that way, we believe the noise performance of the silicon based optical sampling system can be improved significantly.



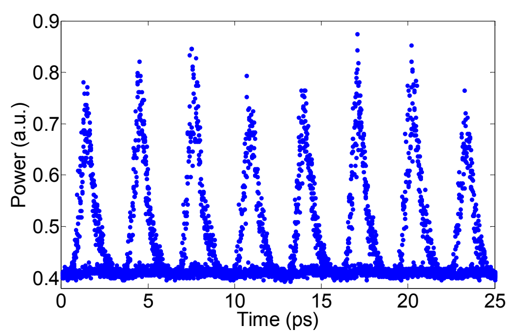


Fig. 3 (Left) Optical spectrum after silicon waveguide. (Right) Eye-diagram of 320 Gb/s data signal.

4. Conclusions

In this paper, we successfully demonstrate a silicon waveguide based ultra-fast all-optical waveform sampling system. This optical sampling system uses a free running pulsed laser, with a CNT-based mode-locker, as the sampling source and a 5 mm long silicon waveguide as the nonlinear sampling gate. The clear 320 Gbit/s eye diagram shows it is promising to use this silicon based ultra-fast optical sampling system in future Tbit/s optical communication systems.

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