40 Gbit/s serial data signal regeneration using self-phase modulation in a silicon nanowire

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***Abstract*— We experimentally demonstrate self-phase modulation based all-optical regeneration of a 40 Gbit/s serial data signal in a silicon nanowire. Bit error rate characterization shows 2 dB receiver power improvement.**

Keywords- all-optical regeneration; self-phase modulation; Silicon nanowire.

I. Introduction

Silicon waveguides for optical data signal processing obtained considerable research interest in the past several years, due to its high nonlinearity, wide bandwidth, potential of compactness, complementary metal-oxide-semiconductor (CMOS) compatibility and low cost. Ultra-fast nonlinear Kerr effects, including four-wave mixing (FWM), cross phase modulation (XPM) and self-phase modulation (SPM), are employed to realize ultra-fast switching in order to process high-speed data signals. Therefore, the highly nonlinear silicon waveguides have become promising candidates for high speed data signal processing. Unfortunately, there exists unavoidable two-photon absorption (TPA) at telecommunication wavelengths in silicon. Because the recovery time of the free carriers generated through TPA is relatively long (~ns time scale), the free-carrier absorption (FCA) will be harmful to the nonlinear Kerr effects, especially at high speed. However, the silicon waveguides with cross-section of several hundred nanometer dimensions, so called silicon nanowires, are dispersion engineered. By designing the dispersion of silicon nanowires, the conversion efficiency and bandwidth of FWM can be optimized. Silicon nanowires have been used to realize several optical data signal processing, for example 10 Gbit/s all-optical data signal regeneration [1], 160 Gbit/s [2], and 1.28 Tbit/s [3], signal demultiplexing, 640 Gbit/s signal wavelength conversion [4] and 1.28 Tbit/s waveform sampling [3]. Most high-speed demonstrations have been based on FWM, but XPM and SPM are also useful effects.

In this paper, we experimentally demonstrate all-optical signal regeneration of a 40 Gbit/s serial data signal using SPM in a silicon nanowire. Bit error rate (BER) performance is measured to validate the signal regeneration.

II. Experimental Setup

The signal regeneration scheme employs the Mamyshev method, which is based on SPM induced spectral broadening and subsequent offset filtering [5]. The nonlinear device for spectral broadening is a dispersion engineered silicon nanowire with dimensions of 240 nm (height) × 450 nm (width) × 5 mm (length). The width at the end of the silicon nanowire is tapered from 450 nm to a tiny tip end of 40 nm so that the guided mode will expand into a polymer waveguide, which surrounds the SOI waveguide and the taper. The data signal will be coupled into the polymer and then the silicon waveguide through tapered fiber. The measured propagation loss is 4.3 dB/cm and the fiber-to-fiber loss of the device is 5 dB.

Fig. 1 shows the experimental setup for the silicon nanowire based all-optical regeneration of a 40 Gbit/s serial data signal. An erbium-glass oscillating pulse-generating laser (ERGO-PGL) generates a 10 GHz pulse train with central wavelength at 1542 nm and a 1.5-ps full-width at half-maximum (FWHM) pulse width. The 10 GHz pulse train is launched into a 200-m dispersion-flattened highly non-linear fiber to generate a supercontinuum based on SPM. At the output of the DF-HNLF, the broadened spectrum is filtered with a 3 nm optical band pass filter (OBF) centered at 1553 nm to generate 10 GHz pulses for the data signal. A Mach-Zender modulator encodes a 10 Gbit/s data sequence (PRBS 2^{31}-1) on the pulse train and the 10 Gbit/s data signal is multiplexed to 40 Gbit/s by a passive fiber delay polarization maintaining multiplexer (MUX). The generated 40 Gbit/s optical data signal is amplified by an erbium-doped fiber amplifier (EDFA), then filtered by a 3 nm OBF and finally launched into the silicon nanowire through a 3-dB optical coupler (OC). A polarization controller (PC) is used to align the data signal to the TE-like mode of silicon nanowire. The average power of data signal coupled into the silicon nanowire is measured to 17.5 dBm. The data signal at the input of silicon nanowire has 1.5 ps FWHM pulse width, which gives input peak power of 28.5 dBm. This value is well below the two-photon absorption (TPA) threshold [5],

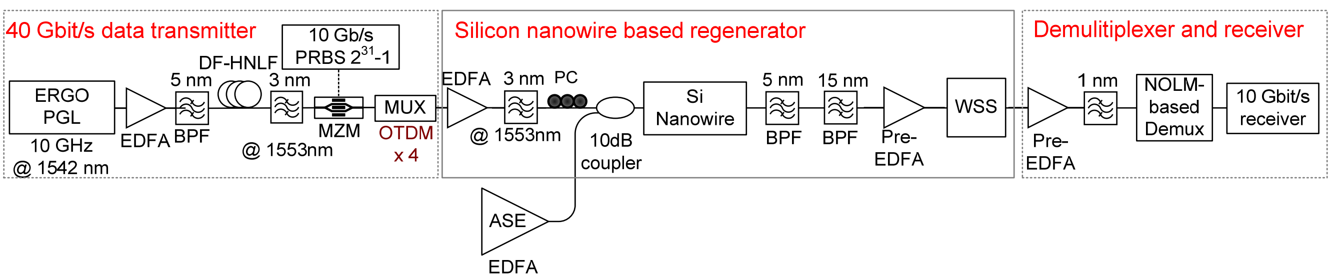

Figure 1. Experimental setup of silicon nanowire based all-optical signal regeneration.

therefore the TPA and resulting carrier effects are negligible.

To achieve a degraded data signal without transmission, noise is added to the 40 Gbit/s data signal artificially. A broadband amplified spontaneous emission (ASE) noise with power level of -1.7 dBm is launched into the silicon nanowire together with the data signal. The bias voltage of the Mach-Zender modulator is adjusted to 1.1 V to add “noise” on the ‘0’ level to the data signal.

At the output of the silicon nanowire, a 5 nm OBF and a 15 nm OBF are cascaded and used to suppress the original data signal. After an EDFA, a wavelength selective switch (WSS) is used to offset filter the data signal. The central

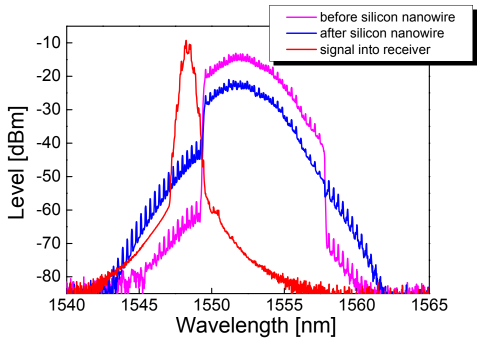

Figure 2. Optical spectra of the 40 Gbit/s data signal, measured before and after the silicon nanowire and before the demultiplexer.

wavelength of the regenerated data signal is selected at 1548.3 nm. By tuning the bandwidth of the WSS, the output pulses can have different pulse duration. Here, the bandwidth is selected to 0.6 nm. Fig. 2 shows the spectra measured during the experiment. The regenerated 40 Gbit/s data signal is demultiplexed to four 10 Gbit/s data signal channels by using a NOLM based demultiplexer. Finally the regenerated 10 Gbit/s data signal is sent into a pre-amplified receiver and the BER performance is measured.

III. EXPERIMENTAL RESULTS

The measured BER performance is shown in Fig. 3. BER curves of the back-to-back (B2B) data signal, degraded data signal and regenerated data signal are shown in the figure. Compared to the B2B data signal (black square), the degraded data signal (red dot) has a 6 dB power penalty at error-free level of 10^{-9}. Moreover, the degraded data signal shows an error floor. After regeneration (green triangle), the receiver power at 10^{-9} achieves 2 dB improvement and there

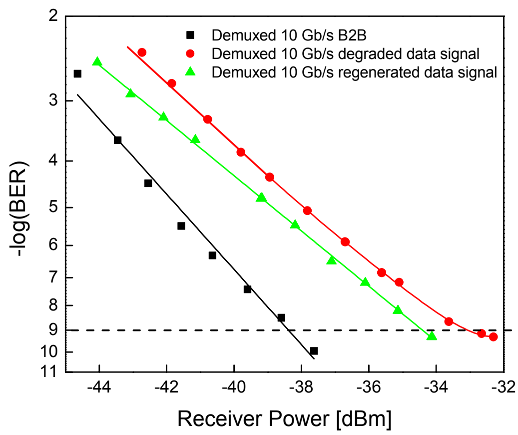

Figure 3. BER performance of the silicon nanowire based regenerator. A 2 dB improvement of the receiver power is achieved at 10^{-9}.

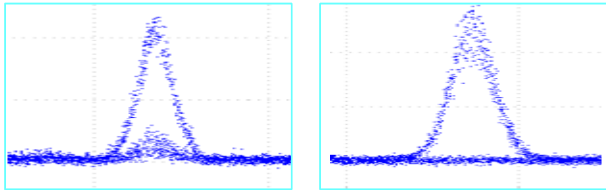

Figure 4. Eye-diagrams. (left) degraded data signal. (right) regenerated data signal.

is no sign of an error floor. The slope of the BER curve is shallower than the back-to-back, which is expected to be due to some noise on the 1 level.

Fig. 4 shows the eye-diagrams of the degraded (left) and regenerated (right) data signal. From the eye-diagram, we can see that the ‘0’ level noise is removed considerably. However, the fluctuation on ‘1’ level is not suppressed. We believe this is caused by the limited launch power into the silicon nanowire. The polymer waveguide, surrounding the silicon waveguide, cannot endure too high input average power (no higher than 20 dBm). Therefore, the power into the silicon nanowire cannot reach the critical intensity level to broaden the spectrum sufficiently. This might be solved by compressing the data signal pulse duration to obtain higher peak power or by using other polymer material to increase the maximum input power level.

IV. CONCLUSION

We have successfully demonstrated all-optical regeneration of a 40 Gbit/s serial data signal using SPM in a silicon nanowire. The measured BER performance shows a 2 dB receiver power improvement and also shows that the error floor is removed.

V. ACKNOWLEDGMENT

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