Broadband Wavelength Conversion of 10-Gb/s DPSK Signals in Silicon Waveguides

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Abstract: We demonstrate for the first time four-wave mixing based wavelength conversion of phase modulated optical signals in dispersion-engineered silicon waveguides. Error-free operation and 1-dB power penalties are experimentally obtained for 10-GB/s DPSK wavelength-converted signals.

1. Introduction

With the ever increasing bandwidth demands in optical communications, wavelength division parallelism as well as single channel bit-rates will have to aggressively scale to provide Tb/s aggregate bandwidths. Advanced modulation formats relying on both phase and amplitude modulation of data onto optical signals provide higher single-channel bit-rates as well as improved spectral efficiency, enabling higher wavelength-parallel channel density compared to the traditional on-off keying (OOK) formats. As both symbol rate and modulation complexity continue to evolve, transceiver-based signal manipulation systems will become ever more complex and power demanding. Parametric optical processing platforms provide an attractive power efficient as well as format transparent implementation alternative for signal manipulation functionalities such as wavelength conversion, wavelength multicasting, and temporal demultiplexing. Enabling all-optical devices leveraging four-wave mixing (FWM) for all-optical parametric processing have been demonstrated in highly-nonlinear fiber (HNLF) [1], III-V semiconductors [2], chalcogenides [3], as well as silicon [4-6].

The potential for low-cost mass production leveraging complementary metal-oxide-semiconductor (CMOS)-compatible silicon photonic devices have enabled the emergence of small-footprint low-cost silicon waveguides for FWM applications, capable of being dispersion engineered to optimize performance [7]. Wavelength conversion bandwidth of 800 nm [8] has been demonstrated with continuous light, showing the potential for ultra-broadband parametric processing systems based on silicon technology. Previous wavelength conversion demonstrations of optical data in silicon waveguides have focused on OOK modulated signals for both non-return-to-zero (NRZ) signals as well as pulsed return-to-zero (RZ) formats [4-6]. However, the wavelength conversion performance of phase modulated signals in silicon waveguides has yet to be investigated. In this work, we demonstrate wavelength conversion of high-speed differentially-phase-shift-keyed (DPSK) signals in silicon waveguides across 100-nm wavelength range, validating the capacity of these silicon waveguides for ultra-broadband, format transparent parametric processing. We wavelength convert 10-Gb/s DPSK signals over varied probe-idler separations, and experimentally evaluate the performance of this functionality by measuring bit-error-rate (BER) curves. We demonstrate error-free (defined as having BERs less than 10^{-12}) operation of wavelength conversion, and constant 1-dB low power penalty over a range of probe-idler separations spanning the ITU S-, C-, and L-Bands.

2. Experimental setup

The device used here is a silicon waveguide of 1.1-cm length and a 290-nm × 720-nm cross section, fabricated at Cornell Nanofabrication Facility using electron-beam lithography followed by reactive-ion etching. Each end of the waveguide has an inverse-taper mode converter for efficient coupling to tapered fibers. The zero-group-velocity-dispersion (ZGVD) wavelength for this waveguide was calculated to be approximately 1577 nm [7].

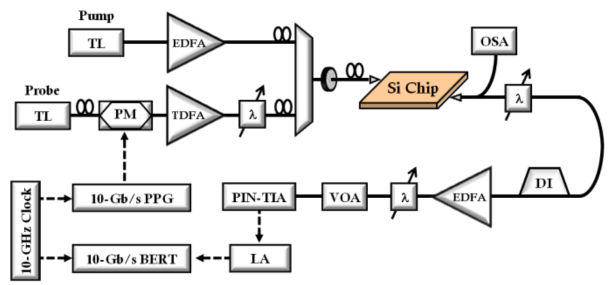

Fig. 1 Diagram of experimental setup.

The experimental setup is shown in Fig. 1. A continuous-wave (CW) probe from a tunable laser (TL) was modulated by a phase modulator (PM) driven with a 10-Gb/s 2^{31}-1 pseudo-random bit sequence (PRBS) pattern from a pulsed-pattern generator (PPG) to generate a DPSK-modulated signal. A CW 1552.5-nm pump was created by amplifying the output of a TL using an erbium-doped fiber amplifier (EDFA). The modulated probe signal was amplified using a thulium-doped amplifier (TDFA), filtered (λ), and combined with the pump. Both probe and pump were set to TE polarization before entering the waveguide. The optical signals egressing from the waveguide were examined on an optical spectrum analyzer (OSA). The converted data signal was recovered using filtering and amplification stages. It was then demodulated by a delay interferometer (DI) with 95-ps delay between the two arms and inspected using a digital communications analyzer (DCA), received using a photodetector (PIN-TIA) followed by a limiting amplifier (LA), and examined on a BER tester (BERT). A variable

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optical attenuator (VOA) was used to vary the optical power incident on the receiver for the BER measurements. Demodulated back-to-back eye diagrams and BER curves were recorded directly before the probe was combined with the pump, using the same DI setup to demodulate the signals.

3. Experiments and results

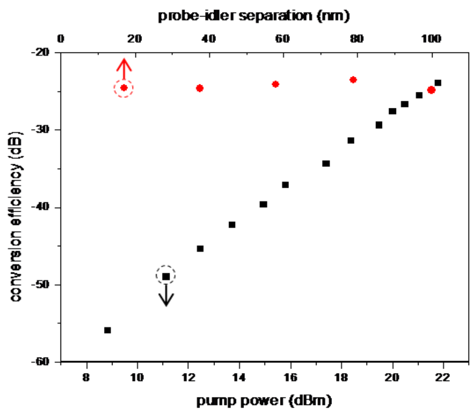

Fig. 2 Conversion efficiency versus probe-idler wavelength separation with a pump wavelength of 1552.5 nm and a pump injection power of 21.5 dBm (red dots); Conversion efficiency as a function of injected pump power with 1552.5-nm pump and 1504-nm probe (black dots).

We initially inspected the conversion efficiency of the modulated data as a function of the pump power and the probe-idler separation as shown in Fig. 2. With the pump set at 21.5-dBm power, we varied the probe wavelength between 1544 and 1504 nm, corresponding to conversion ranges between 17 nm and 100 nm showing constant -24 dB conversion efficiency for this pump setting. We then set the probe at a wavelength of 1504 nm while varying the pump power and verify the quadratic relation between pump power and conversion efficiency for the inspected pump powers. We proceeded to record eye-diagrams (Fig. 3b) and BERs for both probe and converted signals at probe wavelength settings at 1504, 1514, and 1524 nm (Fig. 3a) corresponding to wavelength conversions of 100, 79, and 58 nm respectively. Open eye-diagrams as well as a constant minimal power penalty of 1 dB for all settings were experimentally obtained (Fig. 4).

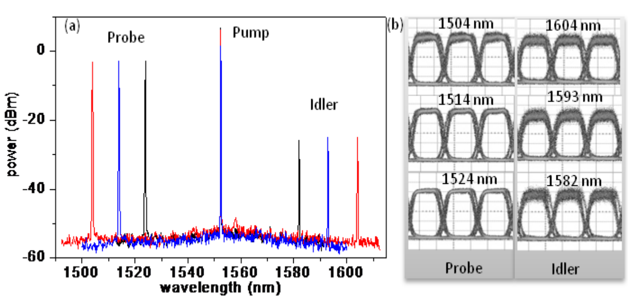

Fig. 3 (a) Overlaid Spectra of wavelength conversion recorded directly after the chip. Probe wavelengths are set to 1504, 1514, and 1524 nm, respectively. (b) Eye diagrams of back-to-back (probe) and wavelength converted signals (idler) with different probe-idler separations.

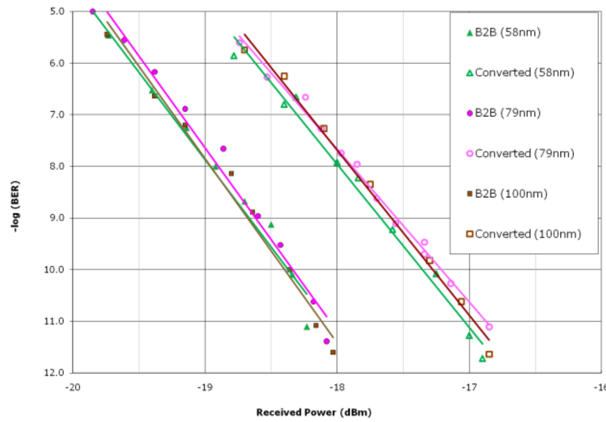

Fig. 4 10-Gb/s BER curves of back-to-back and wavelength-converted signals with constant 1-dB power penalties for probe-idler separations of 58, 79, and 100 nm.

4. Conclusion

We have demonstrated a broadband wavelength conversion of 10-Gb/s DPSK signal over 100 nm using FWM in silicon waveguides, showcasing the capability to perform phase-preserving operations at high bit rates in chip-scale devices over wide conversion ranges. We observed constant 1-dB power penalty after wavelength conversion for all the examined probe-idler separations. The results affirm the feasibility of format-transparent continuous wavelength converters operating over the full ITU S-, C-, and L-bands using silicon-based FWM devices.

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5. References

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