Demonstration of 300 Gbps Error-Free Transmission of WDM Data Stream in Silicon Photonic Wires

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Abstract: We present the first experimental demonstration of error-free (bit error rates < 10^{-12}) transmission of a 300-Gbps WDM data stream through a 2-cm-long silicon photonic wire using 24 C-band channels, each modulated at 12.5 Gbps.

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1. Introduction

SOI is a preferred platform for ultra-dense on-chip integration of photonic and electronic circuitry because of its tight light confinement and its compatibility with CMOS fabrication. Many active and passive components have been envisioned and successfully fabricated in this material system [1-5]. An important next step in this work is to build an on-chip ultrahigh-bandwidth silicon photonic network for an intra-chip or chip-to-chip interconnection network, which would provide an attractive solution to an electronic bottleneck in high-performance computing-system interconnects [6]. Silicon photonic wires, which have very low scattering loss and sub-micrometer dimensions, may serve as the ideal transmission media for networks such as these. Despite the attractiveness of photonic wires for these optical links there are several important questions to be answered regarding their performance under actual system conditions, including the practical importance of free carrier generation at high data rates or the onset of optical nonlinearities in long links and at high data rates.

In this abstract, we present our experimental results showing error-free transmission of twenty-four 12.5-Gbps WDM channels (aggregate data rate of 300 Gbps) through a 2-cm-long silicon photonic wire waveguide. No noticeable signal degradation is incurred on the datstream, in agreement with predictions from previously developed numerical simulations [7-9]. Considering the size of a conventional semiconductor dice (~ 1cm×1cm), this waveguide length is sufficient to route to any on-chip destination, regardless of the network topology. To our best knowledge, this is the highest data rate that has ever been demonstrated in silicon photonic wires.

2. Silicon photonic wire

(a) (b)

Fig.1 Silicon photonic wire waveguides: (a) cross-section view and (b) overhead view with 1 mm scale.

The silicon photonic wire that we used in the experiment is a single-mode waveguide with cross-section A_0 = 220nm × 445nm as shown in Fig. 1. The devices were fabricated using the CMOS production line at the IBM T.J. Watson Research Center. Each end of the waveguide has an inverse taper mode-converter covered with index matching polymer, which allows efficient coupling. The waveguide length is 2.1 *cm*. The measured intrinsic waveguide loss, α_{in}, is 1.5 dB/cm for TE polarization near λ = 1550 nm. The group velocity dispersion (GVD) coefficient β_2 is –3.97 ps^2/m (D = 3.2 ps/nm-m) and the third order dispersion (TOD) coefficient β_3 is –0.73 ps^3/m at 1537 nm [9]. The nonlinear coefficient, $\Gamma = (2.35\times10^4 + i4.94\times10^3)$ pm^2V^{-2}, is calculated using the experimental value of the bulk Kerr coefficient n_2 and TPA absorption coefficient [9].

3. Experiment and discussion

The experiments demonstrate the feasibility of integrated silicon photonic networks by confirming the excellent signal integrity of an ultrahigh-bandwidth data stream that has propagated over a 2-cm-long silicon photonic wire. The setup includes 24 lasers operating with 100-GHz (0.80-nm) channel spacing multiplexed onto a single fiber (Fig. 2a). The wavelengths correspond to channels C22 (1559.79 nm) through C45 (1541.35 nm) of the ITU C-band. The entire spectrum with a span of approximately 19 nm is simultaneously amplitude modulated with a 12.5 Gbps non-return-to-zero (NRZ) on-off-keying (OOK) data stream encoded with a 2^{31}-1 pseudo-random bit sequence (PRBS) using a $LiNbO_3$ modulator. The parallel wavelength channels are decorrelated by over 400 ps/nm in a 24-km length of single-mode fiber to avoid pattern-dependent effects. The low-power communications lasers are boosted by an EDFA. The signal is coupled in and out of the photonic wire using tapered fiber lenses aligned with the inverse polymer mode converter. A second EDFA is used at the output to compensate power losses. Finally, a 100-GHz optical grating filter selects the desired channel from the broadband signal to be sent to the high-speed receiver, which is followed by a bit error rate (BER) tester. Error-free operation (BER < 10^{-12}) was observed on each channel, and the eye diagrams at the output of the device remain virtually indistinguishable from those at the input (Fig. 2b).

The smallest temporal pulse-width, T_0, used in the experiment is about 80ps. For this pulsewidth, the GVD length, $L_D=T_0^2/|\beta_2|=1.6\times10^5\,cm$, and the TOD length, $L_D=T_0^3/|\beta_3|=7.0\times10^7\,cm$, are many orders of magnitude longer than the waveguide length. Therefore, the dispersion effects can be ignored. The total input power inside the waveguide is estimated to be about 1.0 mW. Although the nonlinearity of silicon photonic wires is very strong, at this power level, nonlinear effects will not cause significant impairments to the signal pulses [7-9]. The results shown in Fig. 2 matched very well with this linear propagation assumption. If we significantly increase the bit rate, the total power inside the waveguide may reach a level that two-photon-absorption (TPA) induced free carrier (FC) effects may lead to extra loss and severe temporal and spectral asymmetry in the detected signal. Other χ^3 nonlinear processes, such as cross-phase modulation and four wave mixing may introduce cross-talk among adjacent channels. We are working on experimentally finding the threshold for all these processes.

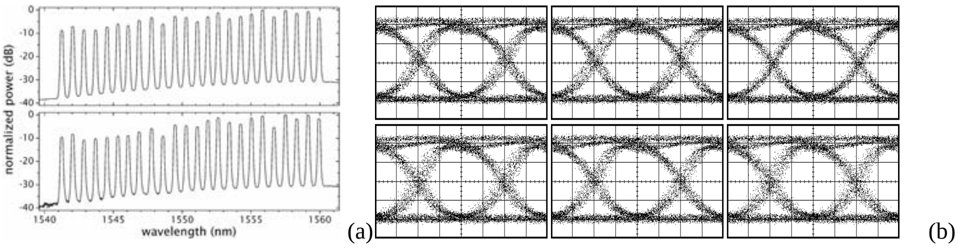

Fig. 2. (a) Spectra of the 24 wavelength channels taken before (top) and after (bottom) propagating through the SOI waveguide and (b) eye diagrams for the received signal before (top) and after (bottom) propagation through the 2-cm silicon wire waveguide. The eye diagrams, from left to right, represent ITU channels C22 (1559.79 nm), C33 (1550.92 nm), and C45 (1541.35 nm) taken with scope settings of 5 mV/div and 20 ps/div.

4. Conclusions

We have experimentally demonstrated 300 Gbps error-free transmission of a WDM data stream through a 2-cm-long silicon photonic wire waveguide. The excellent preservation of signal integrity justifies the usage of silicon photonic wires as backbone transmission media for integrated photonic networks.

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