All-Optical Multi-Wavelength Message Routing for Silicon Photonic Networks

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Abstract: **We demonstrate all-optical switching of 20 wavelength channels simultaneously in a silicon broadband comb switch, and perform single-channel BER measurements through both ports.**

Introduction

With recent noteworthy advances in nanoscale fabrication and dense integration, silicon photonic device technologies have emerged as a viable solution in a multitude of short-reach applications currently dominated by electronic interconnects. Optical technologies supporting the immense bandwidth allocated by wavelength division multiplexing (WDM) and offering low-power switching capabilities may alleviate bandwidth and power limitations in existing chip-to-chip and future on-chip networks [1]. The silicon-on-insulator (SOI) platform is an attractive material system for realizing these photonic integrated circuit (PIC)-based interconnection networks due to its high index contrast and compatibility with CMOS integration [2–5]. Microring resonators present viable building blocks for these systems and have already been shown to perform passive filtering operations, in addition to electro-optic and all-optical switching and modulation [2–5], all within the context of the SOI platform. A low-power, high-speed, compact switch capable of operating over a large spectral bandwidth represents a key building-block functionality for routing WDM data in optical networks.

The device structure discussed here, previously reported in [3–5], comprises a ring resonator coupled to two parallel waveguides (Fig. 1a). Input light on resonance with the ring is coupled to the drop port of the device, and light off resonance propagates to the through port. The wavelengths of the ring's resonant modes are blue-shifted simultaneously by injecting electronic carriers into the device through the free-carrier plasma dispersion effect. When the wavelength of an optical data signal is aligned on resonance, the presence of a carrier-generating pump source switches the signal from the drop port to the through port. Removal of these carriers directs the signal back to the drop port. Carriers may be injected using an optical pump [3] or an electrical signal applied across a p-n junction surrounding the waveguide [2].

In the work presented here, we switch a multi-wavelength packet cohesively by leveraging the device's small free-spectral range of 0.8 nm, allowing many resonator modes to each switch one channel of a WDM signal simultaneously. Moreover, the energy required to switch many channels is the same as that required to switch a single channel.

All-optical switching of two continuous-wave (cw) wavelengths has been previously demonstrated [3]. Additionally, a 160-Gb/s data stream was passed through the switch passively (with no applied pump), and the bit-error-rate (BER) degradation due to inter-channel crosstalk within the ring was found to be negligible when scaling from one to 16 wavelength channels [4].

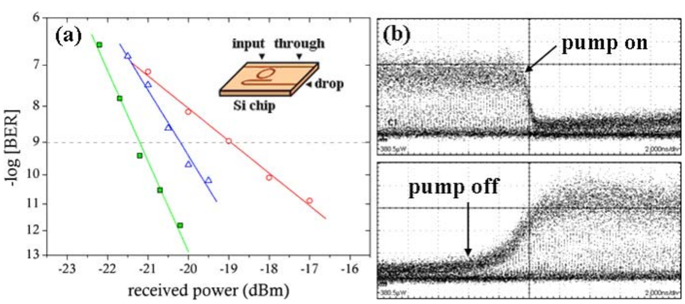

Fig. 1. (a) BER curves for a signal exiting through (blue, △) and drop (red, ○) ports while switch is active; back-to-back through waveguide with no pump signal present (green, ■); switch layout inset. (b) Scope traces of switched optical data egressing from drop port, illustrating switching ratio and transition times, using a 2-ns/division time scale.

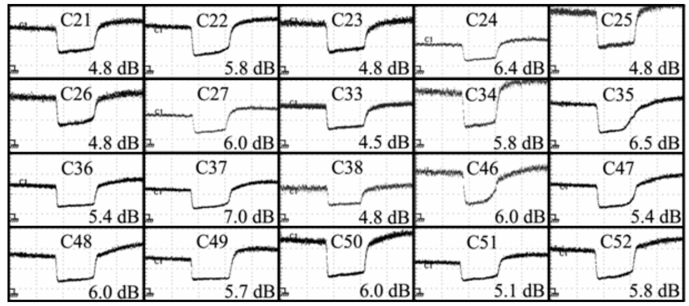

Fig. 2. Waveforms exiting the drop port of the device under active operation, with corresponding ITU channel labels and extinction ratios, using a 32-point average and 10-ns/division time scale.

We further characterized the passive insertion losses and extinction ratios of the switch along both ports [5]. Here, we investigate the BER performance of all-optically switched data, and demonstrate full switching of 20 wavelengths simultaneously.

Results and Conclusion

The experimental setup for performed BER measurements is depicted in [5]. The optical pump used throughout the experiments generates free carriers through two-photon absorption, causing all modes to shift when the pump it is enabled. The switching ratio and transition times of the probe after exiting the drop port (Fig. 1b) may be improved with a more optimal pump configuration, and the transition times can be further reduced by applying techniques described in [2].

The BERT is first gated to take measurements only during the arrival of data exiting the drop port (pump off). While a single channel is actively switched through the device, error-free operation (BER of less than 10^{-12}) is first verified; BER measurements are then performed (Fig. 1a). The BERT is then gated to take measurements only during the arrival of the data exiting the through port (pump on). Again, error-free operation is verified, and a BER curve is recorded (Fig. 1a). Finally, the back-to-back BER curve is taken by coupling into the reference waveguide with no applied pump (Fig. 1a). Power penalties of 1 dB and 2.3 dB are measured at the through and drop ports, respectively, under active operation at near-GHz speeds.

Multi-wavelength switching (Fig. 2) is demonstrated by simultaneously passing 20 WDM channels through the drop port in the presence of the pump signal. The wavelengths span 25 nm, comprising channels C21–C27, C33–C38, and C46–C52 of the ITU C-Band grid. The switching extinction ratios are somewhat degraded by EDFA noise, but nevertheless range from 4.5 dB to 7.0 dB with an average value of 5.6 dB.

Based on previous evidence suggesting negligible BER degradation from wavelength-channel scaling [4], the broadband loss uniformity reported in [5], and the demonstrated low-penalty active operation, the device can be envisioned to function as a viable high-speed broadband switch for integrated silicon photonics used in chip-to-chip and intra-chip networks.

KB, AB, and BGL acknowledge support from the NSF under contract CCF-0523771. The work of ML and PD was part of the Interconnect Focus Center Research Program at Cornell University, supported in part by MARCO, Structured Materials Inc. under Grant 41594, and NSF CAREER Grant 0446571.

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