250 Gb/s Multi-Wavelength Operation of Microring Resonator-Based Broadband Comb Switch for Silicon Photonic Networks-on-Chip

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Abstract

A 250-Gb/s multi-wavelength signal dynamically routed through a high-speed 1×2 silicon switch advocates low-power networks-on-chip, with power penalties and extinction ratios investigated.

Introduction

Silicon photonic device technologies are already bearing fruit as viable solutions to a multitude of short-reach applications currently dominated by electronic interconnects. For instance, low-power optical technologies supporting the immense bandwidth allocated by wavelength division multiplexing (WDM) may alleviate bandwidth and power limitations in existing chip-to-chip networks and future on-chip networks [1]. The silicon-on-insulator (SOI) platform is becoming the material system of choice for realizing ultra-small-footprint photonic integrated circuit (PIC)-based interconnection networks, due to its high index contrast and compatibility with CMOS integration [2–6]. Microring resonators act as building blocks for these systems and have already been shown to perform many crucial operations within the context of the SOI platform [2–6]. Moreover, microrings allow for a multi-wavelength ultrafast switch, which is required for message routing in these networks. The switch previously reported in [3–5], is now operated with signals consisting of the highest reported aggregate data rate, 250 Gb/s, and extinction ratios and power penalties are investigated. A similar fifth-order coupled-resonator system has also been demonstrated [6], and provides higher thermal stability, and larger per-channel bandwidths.

Broadband comb switch

The device structure discussed here comprises a ring resonator coupled to two parallel waveguides (Fig. 2 inset). Input light on (off) resonance with the ring is coupled to the drop (through) port of the device. The wavelengths of the ring's resonant modes are simultaneously blue-shifted by injecting electronic carriers into the device [3]. When the wavelength of an optical 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. This may be accomplished with an optical pump [3] or an electrical signal applied across a p-n junction surrounding the waveguide [2].

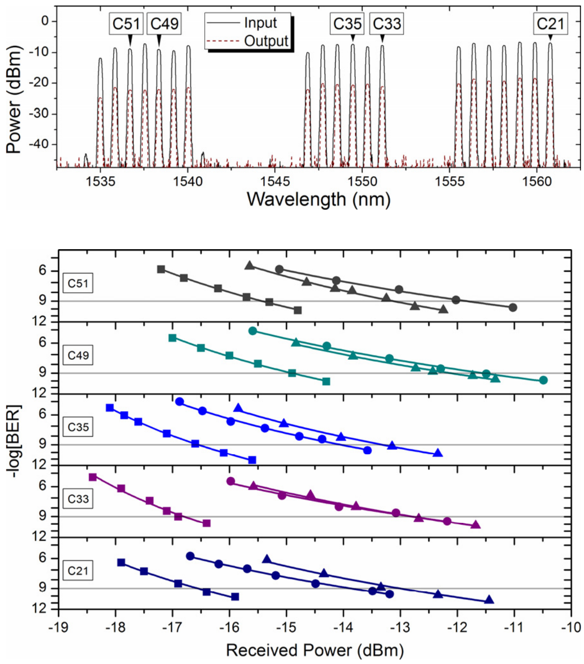

Figure 1: (top) WDM signal input/output spectra at drop port. (bottom) BER curves for through (▲), drop (●), and reference (■) ports for five of 20 channels.

The device's small free-spectral range of 0.8 nm, which allows many resonator modes to each switch one channel of a WDM signal simultaneously, is leveraged to switch a multi-wavelength packet cohesively. The energy required to switch many channels is the same as that required to switch a single channel.

Previously, a 160-Gb/s data stream was passed through the switch 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]. Additionally, the BER performance of all-optically switched data for a single channel has been demonstrated (with power penalties as low as 1 dB), and the ability to switch 20 cw wavelength channels has been shown [5]. Here, we demonstrate, for the first time, all-optical simultaneous high-speed switching of a 250-Gb/s data rate using 20 wavelength channels, each modulated at 12.5 Gb/s. Moreover, we examine the switching extinction ratio with varying pump power.

Multi-wavelength BER measurements

The experimental setup for the performed BER measurements is similar to the experimental setup used for BER measurements in [5], apart from the use of 20 wavelength channels multiplexed together using a dense wavelength-division multiplexer (DWDM), simultaneously modulated at 12.5 Gb/s using a pulse pattern generator (PPG), and decorrelated by 25 km of single-mode fiber. The pump, operating near the wavelength of 1533 nm with an average injected power of 18 dBm and externally modulated using a data timing generator (DTG), generates carriers through two-photon absorption. Before entering the chip, the signals pass through a fiber polarizer, selecting the TM-like polarizations. Each selected probe signal is analyzed with a communications signal analyzer (CSA) and a BER tester (BERT), which is synchronized to the PPG with a 12.5-GHz clock.

The pump consists of 20-ns pulses recurring every 82 ns. The wavelength channels, spanning more than 25 nm, comprise channels C21–C27, C33–C38, and C47–C53 of the ITU C-Band grid (Fig. 1). With all 20 wavelength channels actively switched through the device, the BERT is gated to take measurements only during the arrival of data exiting the drop (through) port, during the transitions when the pump is off (on). BER measurements are subsequently performed for five of these channels, for both ports (Fig. 1). Finally, the back-to-back BER curves are taken by coupling into the reference waveguide with no applied pump (Fig. 1). Measured power penalties at the drop (through) port for the five channels range from 2.5 dB (2.3 dB) to 4.1 dB (4.1 dB), with an average of 3.3 dB (3.2 dB). The channel-to-channel variation is a result of the fine wavelength tuning that is required of the distributed-feedback (DFB) lasers in order to provide optimal switching ratios and constant powers over the duration of the switched message. Furthermore, at least 1.2 dB of each measured power penalty is expected to result from narrowband filtering imposed by the resonator modes on the channel's signal spectrum [4]. Devices such as those reported in [6], provide a promising path toward alleviating these tight wavelength requirements by providing broader per-channel bandwidths.

Extinction ratio and pump power

Replacing the mutli-channel data source with a single cw wavelength channel, extinction ratios are measured at both ports for varying injected pump powers (Fig. 2). The extinction ratios are improved on both ports with larger pump powers. At the drop port, the extinction ratio is improved by 6.5 dB with the added 12 dBm of pump power; at the through port, the extinction ratio is improved by 11.5 dB (to the point of limiting our ability to measure further improvement) with the added 6.5 dBm of pump power. The switching ratios and transition times, although already adequate for proper operation, may be further improved with a more optimal pump configuration described in [2].

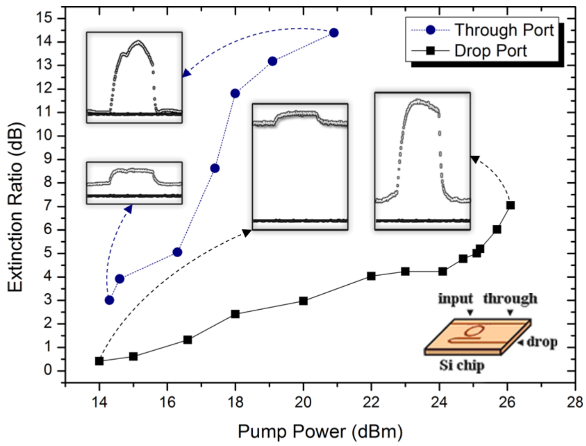

Figure 2: Measured extinction ratios with varying pump power for through (●) and drop (■) ports with insets of corresponding extinction ratios (using a 16-point average) and device layout.

Conclusions

We demonstrate, for the first time, all-optical simultaneous switching of a 250-Gb/s data rate using 20 wavelength channels spanning more than 25 nm in a silicon photonic switch. Average power penalties of 3.2 dB and 3.3 dB are measured for five channels at the through and drop ports, respectively, under active operation at near-GHz switching speeds. This high-speed, broadband device is thus envisioned to perform well in an integrated silicon platform, allowing for the fruition of high-bandwidth communication within low-power photonic networks-on-chip.

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