Silicon Microring Resonator-Based Broadband Comb Switch for Wavelength-Parallel Message Routing

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Abstract: **We demonstrate error-free propagation of wavelength-parallel 160-Gb/s optical data in a broadband silicon microring resonator-based comb switch, and observe no power penalty increase associated with inter-channel crosstalk when scaling from one to 16 wavelength channels.**

Introduction

As the performance of electronic on-chip and chip-to-chip interconnects becomes increasingly constrained by power and speed limitations, photonic integrated circuits (PICs) emerge as an attractive solution to the problems of on-chip connectivity and off-chip bandwidth [1]. The silicon-on-insulator (SOI) platform has gained significant attention, becoming the material system of choice for integrated optical interconnects owing in part to its favorable optical properties, enabled by high index contrast, and its compatibility with electronic integration [2–4]. Microring resonators present valuable building blocks for these systems, and have already been shown to perform passive operations such as filtering and multiplexing, as well as active functions including electro-optic, all-optical, and thermo-optic switching and modulation [2–4].

The device discussed here, previously reported in [4], consists of a microring with resonator modes spaced by approximately 100 GHz, intended for use in wavelength-division-multiplexed (WDM) systems. This spacing allows the ring to operate as a comb switch on a broadband, wavelength-parallel data stream in much the same way a smaller-diameter ring would act upon a single-channel signal. In fact, all-optical switching of a two-wavelength-channel signal has been recently demonstrated using the device [4]. In this paper, we demonstrate the propagation of very-large-bandwidth data streams (160 Gb/s) through the ring resonator-based comb switch, and measure the signal degradation due to wavelength crosstalk. Moreover, an analysis of the maximum possible bandwidth of this device is performed, based on single-channel power penalty measurements conducted as a function of data rate.

Experimental Setup

The experimental setup (Fig. 1) consists of 16 separate laser sources, one for each wavelength channel, multiplexed together with a 100-GHz channel spacing and externally modulated with a 10-Gb/s non-return-to-zero (NRZ) on-off-keyed (OOK) signal, encoded using a pseudo-random-bit-sequence (PRBS) of length 2^7-1, generated by a pulse pattern generator (PPG). Leaving the modulator, the 160-Gb/s signal travels through a 25-km decorrelator, and couples into the nanotapered SOI waveguide on the silicon chip, through a tapered fiber.

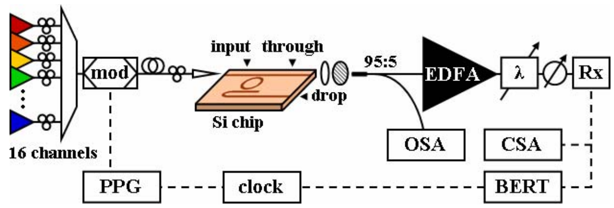

Fig. 1. Diagram of the experimental setup.

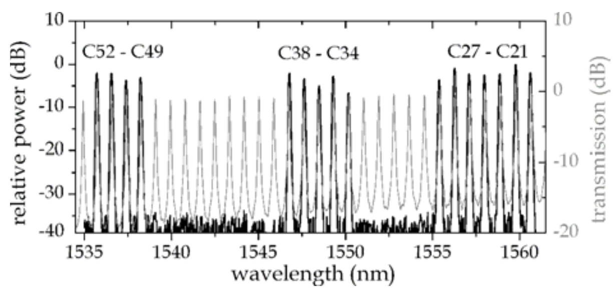

Fig. 2. WDM signal spectrum recorded after the drop port labeled with ITU C-band channel numbers (black, left axis), and relative transmission spectrum of the drop port (gray, right axis).

After exiting the chip, the signal passes through a polarizer, which is used to select the TM-like polarization, and is collimated and collected into a fiber. The signal then continues to propagate through an erbium-doped fiber amplifier (EDFA), a tunable grating filter (λ), and a variable attenuator, and is then received by a high-speed receiver (Rx) with a transimpedance amplifier/limiting amplifier (TIA/LA) pair. The signal is analyzed with a communications signal analyzer (CSA) and a bit-error-rate (BER) tester (BERT), which is synchronized to the PPG through a 10-GHz clock. A small part of the signal power (5%) is tapped-off before the EDFA, and is connected to the optical spectrum analyzer (OSA) for monitoring.

The device used in this experiment is a broadband all-optical comb switch, comprising a ring resonator coupled to two straight waveguides; one is the input port and through port, and the other is the drop port. On resonance, light is coupled into the ring resonator, and is sent to the drop port. Off resonance, light propagates virtually unaffected to the through port. The free spectral range (FSR) of the ring resonator is about 0.83 nm, corresponding to its relatively large diameter of 200 μm. The resonator modes are quite uniform, producing over 32 consecutive channels with extinction ratios better than 15 dB (Fig. 2). Leveraging the relatively small FSR, multiple channels are able to be switched simultaneously for broadband WDM interconnection network routing applications. Since the FSR of the ring is not precisely that

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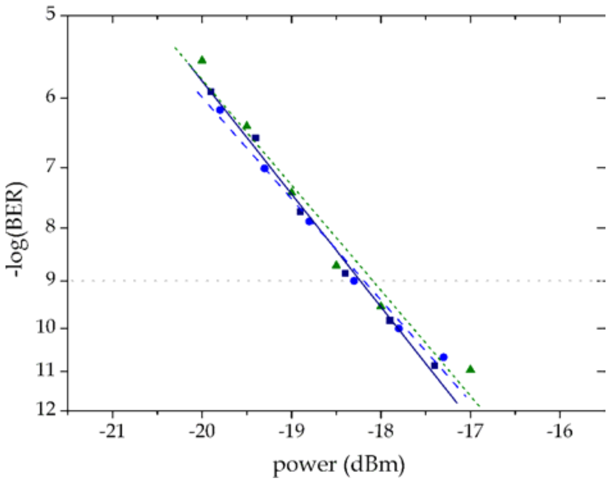

Fig. 3. BER plots recorded at the drop port showing no observable power penalty due to wavelength crosstalk; 16 (■, solid line), 12 (●, long-dashed line), and 1 (▲, short-dashed line) wavelength channel.

of the multiplexer channel spacing, the overlap between the ring resonator modes and the multiplexer passbands was limited in the setup, forming groups of utilizable channels (Fig. 2), comprising channels C21-C27, C34-C38, and C49-C52 of the ITU C-band. A proper overlap would make it possible to utilize many more channels, allowing for an even higher transmission bandwidth.

Results

All 16 channels are first verified to operate error free (defined as having a BER of less than 10^{-12}) at 10 Gb/s, through the drop port of the device (Fig. 1). To measure the increase in power penalty due to wavelength crosstalk within the microring, a BER curve is taken for channel C36 at the drop port of the device when all 16 channels are enabled. The same measurement is then repeated after turning off all channels in the second group (C38-C34) except C36, leaving 12 channels, and taken again after turning off all channels except C36. No significant penalty due to wavelength crosstalk was observed (Fig. 3).

The high performance of the microring, in terms of resonator mode uniformity and wavelength crosstalk, indicates that significantly more wavelength channels could be switched by the device. Thus, the aggregate signal bandwidth that can be routed through the device depends on the allowable data rate per channel. In light of this, the power penalty of the device as a function of the incident optical signal data rate is measured using a similar experimental setup to the aforementioned experiment, except only a single wavelength channel is used. In this case, the overall power penalty is necessary, rather than the change in power penalty as before. Therefore, BER curves are taken on the optical signal passing through the drop port with the wavelength on resonance, and on the signal egressing from the through port with the wavelength off resonance. The power penalty is obtained by taking the difference between the two curves, at a BER of 10^{-9}.

The power penalty is measured for data rates of 5.0,

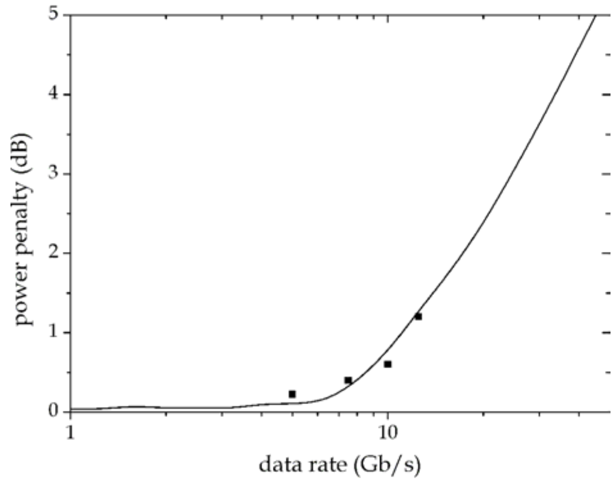

Fig. 4. Measured (■) and simulated (line) single-channel power penalty of the microring resonator as a function of incident optical signal data rate.

7.5, 10.0, and 12.5 Gb/s (Fig. 4), and (due to the ring's low-pass characteristics) increases sharply as the data rate exceeds the resonator bandwidth of about 10 GHz. These measurements are also verified using the model described in [5]. For the current device structure, assuming 40 wavelength channels each modulated at 20 Gb/s, an overall bandwidth of 0.8 Tb/s can be envisioned with a power penalty of less than 2.5 dB. Furthermore, future devices designed with wider bandwidths would enable data rates of 40 Gb/s per channel or more, scaling the bandwidth well past a terabit per second.

Conclusion

We have successfully demonstrated the error-free propagation of data streams totaling 160 Gb/s through a broadband all-optical microring comb switch. Moreover, no increase in power penalty was observed from wavelength crosstalk, a property that will clearly enable more wavelength channels to be transmitted through the device. Based on both measurement and simulation of the single-channel power penalty as a function of data rate, the achievable bandwidth of this device is estimated to be near one terabit per second, but even higher aggregate bandwidths can be envisioned in future devices.

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