Wavelength Locking of a WDM Silicon Microring Demultiplexer using Dithering Signals

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Abstract: A control system utilizing dithering signals is used to demonstrate wavelength locking of WDM channels by a microring filter array. Data measurements verify that the dithering mechanism has a near-negligible effect on filtered data channels.

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The silicon photonics platform promises to bring low-cost, low-energy, and small footprint optical interconnects to a host of applications, most immediately in such environments as local access networks, data center networks, and inter-rack and inter-board interconnects [1-3]. Within the silicon photonics platform, silicon microring resonators are amongst the most promising components. Their resonant functionality allows them to be manifested on the micrometer-scale, resulting in a footprint and energy-efficiency that is orders of magnitude better than traditional optical components. Microring-based devices can be configured to serve as the effective modulators, switches, and filters necessary for optical links. They can also be readily manifested in WDM configurations as shown in Fig. 1a, in which a WDM microring demultiplexer is illustrated filtering corresponding data channels from a WDM stream.

However, the resonant functionality of microrings also makes them susceptible to temperature fluctuations and fabrication offsets [4]. Figure 1b illustrates this predicament for the WDM microring demultiplexer. The microring resonators must be tuned to their initial positions in order to function properly. This is accomplished through the use of integrated heaters, localized resistive elements that thermally tune microring resonators to their resonant wavelengths. Additionally, these integrated heaters can be incorporated into closed-loop control systems to thermally stabilize microring resonators [4].

![Figure 1: (a) Schematic of a WDM silicon microring demultiplexer. (b) Illustration of a scenario in which the microring resonances are not initialized (solid), and their corresponding position (dotted) after they have been tuned to the appropriate resonant wavelengths. (c) The through-port optical response of a microring resonator (top), and the subsequent error signal (bottom) derived using the dithering mechanism.](image-url)

Automated techniques to tune microring resonators are critical for their deployment in commercial optical interconnects. However, tuning microring resonators to their appropriate resonant wavelengths is inherently difficult because their symmetrical optical response (Fig. 1c) is difficult to incorporate directly into a closed-loop feedback system. The solution lies in the generation of anti-symmetric error signals, which can easily be incorporated into wavelength locking and temperature stabilization control systems [5,6]. One of the most efficient methods to derive this error signal is to apply a small periodic signal (known as a dither signal) thermally to the microring resonator [6]. This dithering mechanism has been demonstrated using low-speed analog & digital electronics, and was found to effectively wavelength lock and thermally stabilize microring resonators [6,7].
We demonstrate that the dithering mechanism can be scaled up to a WDM system, specifically that of a WDM microring demultiplexer (as illustrated in Fig. 1a), and validate that the dithering mechanism does not deleteriously affect the high-speed data propagating through the microring resonator. Furthermore, we show that the dithering mechanism is robust enough to deal with challenging scenarios such as that illustrated in Fig. 1b, in which microring resonators may overlap spectrally when locking to their respective resonance channels.

Figure 2: Experimental setup (polarization control not depicted).

The layout of the WDM silicon microring demultiplexer used in our demonstration was topologically similar to the illustration in Fig. 1a, albeit the resonators were designed in a racetrack configuration. The device was fabricated at the Cornell Nanofabrication Facility on a standard silicon-on-insulator (SOI) platform. The fabricated resonators were 5 \( \mu \text{m} \) in radius, with a Q of \( \sim 3000 \). Integrated heaters were formed by depositing NiCr above the cladding of the silicon waveguide. With no power applied to the integrated heaters, the resonant wavelengths of microrings 1, 2, and 3 (corresponding to Fig. 1a) were 1549.50 nm, 1548.76 nm, and 1550.73 nm, respectively.

Our experimental setup is depicted in Fig. 2. LiNbO\(_3\) modulators were used to generate 3 data channels by modulating laser wavelengths at 1550.92 nm, 1552.52 nm, and 1554.13 nm with a 10 Gb/s NRZ 2\(^{31}-1\) pseudo-random-binary-sequence (PRBS). The data on the channels was decorrelated using electrical bit-delays. The data channels, at a power of -3 dBm each, were injected into the bus waveguide of the device using a tapered fiber. The 3 drop ports of the device were probed simultaneously using a 3-channel multi-core fiber (MCF). A 50-50 splitter was used to tap off a portion of each recovered data channel to be received on a slow-speed photodiode (< 100 kHz bandwidth) for use in the implemented wavelength locking system. The remaining portion of the signal was evaluated for data integrity using eye diagrams and bit-error-rate (BER) measurements.

For ease of prototyping, we translated the original analog & digital circuitry implementing the dithering mechanism and corresponding control system [7] to an FPGA-based platform. The detected dithering signals (from the slow-speed photodiodes) are relayed to the FPGA through an ADC. The FPGA interfaces with the individual integrated heater on each microring resonator via a DAC that is driving electrical probes on the silicon photonic chip. Using the error signals derived from the dithering mechanism, the control system initializes the microring resonator array, tuning and locking their resonant wavelengths to the injected data channels.

Figure 3: (a) Voltages applied by the control system to the integrated heaters during the wavelength locking sequence. (b) Measured drop-port responses of the microring resonators when they are in their un-initialized state (solid), and when they are aligned to their respective data channels (dashed).

The sequencing of events is more readily understood by observing the integrated heater voltages during a wavelength locking cycle (Fig. 3a). To perform wavelength locking of a channel, the control system ramps the
voltage on the integrated heater while simultaneously applying a small dithering voltage (a 10-mV 2-kHz square wave in this instance) to produce a thermal dithering on the resonance. Once the error signal is detected the control system halts the voltage ramp and enables the feedback loop, locking the microring resonator to the data channel. To prevent collisions, the wavelength locking of the microring resonators are sequenced (as seen in Fig. 3a) according to their physical order in the microring array. Using this method, the microring resonators can successfully lock to their respective channels, despite needing to cross over each other spectrally (Fig. 3b).

A critical concern is that the dithering of the resonance will affect the integrity of the data channel. To evaluate this we measured eye diagrams and performed BER measurements to contrast the performance of the data channel when manually tuning the resonators (without a dithering signal) versus using the wavelength locking system. The eye diagrams of Fig. 4 show that the data channels are not impacted from the use of the dithering signal. Furthermore, from our BER measurements (Fig. 4c) we found that there were relatively low power penalties of 0.1 dB, 0.0 dB, and 0.3 dB, for data channel 1 (CH1), 2 (CH2), and 3 (CH3), respectively, further validating our claim.

We have demonstrated that the use of dithering signals can be scaled to advanced microring configurations, such as a WDM microring demultiplexer. It should be noted that while in their locked state, the microring resonators are also inherently thermally stabilized [6]. Importantly, our results show that the dithering signal can be kept small enough to enable locking and stabilization while avoiding any deleterious effects on the integrity of the data.

In this demonstration external slow-speed photodetectors were used as part of the control system. However, these components can readily be integrated on the silicon photonic platform, as has been shown previously [6,7]. Additionally, the germanium photodetectors that are often motivated for use as high-speed data receivers [8] can be dual-purposed, with the high-frequency component used for data reception, and the filtered low-frequency component used for the dithering mechanism.

Lastly, we note that while this demonstration occurred on a FPGA-based platform was utilized, the demonstrated control system can effectively translate to simpler low-speed analog & digital circuitry, as was demonstrated for wavelength locking a single microring resonator [7]. The important repercussion is that this control system has the potential to be easily integrated in energy-efficient CMOS technology, either co-packaged or monolithically.

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