Wavelength Locking of Microring Resonators and Modulators using a Dithering Signal

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Abstract *We present a scalable, energy-efficient method to automatically align microring resonators and modulators with laser wavelengths, as well as provide thermal stabilization. The method utilizes a dithering signal to generate error signals that are immune to fluctuations in laser power.*

Introduction

Growing bandwidth needs are motivating the replacement of traditionally electronic links with optical links for applications as diverse as data centers, supercomputers, and fiber-optic access networks. For applications such as these, the silicon photonics platform has received wide attention because of its ability to deliver the necessary bandwidth, and by leveraging its CMOS-compatibility, at a potential economy of scale. In particular, silicon microring resonator based devices exhibit leading metrics on size density, energy-efficiency, and ease of WDM implementation. However, the relatively high thermo-optic coefficient of silicon combined with the wavelength selectivity of microring resonators lends them susceptible to changes in temperature and laser wavelength. The dominant method to resolving this problem uses energy-efficient integrated heaters[1] to tune and stabilize the microring resonance to the laser wavelength. While demonstrations of manual tuning validate the functionality of these heaters, for commercial implementations an energy-efficient and scalable solution to lock and stabilize microring resonators is required.

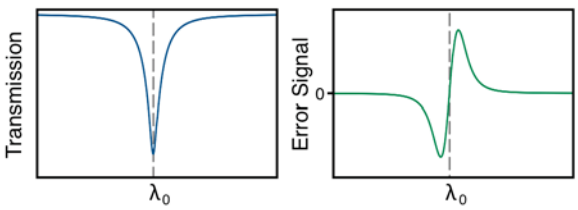

Fig. 1: The optical resonance of a microring resonator (left) and the error signal generated when applying a dithering signal to the microring resonator (right).

There have been several attempted solutions for wavelength locking and thermally stabilizing microring resonators[2-4]. However, no current demonstrated system has satisfied all required criteria, that is, a system that is low-cost and energy-efficient, does not require additional photonic structures, is compatible with WDM implementation, immune to fluctuations in the optical power, and implementable for either passive microring resonators or active components such as microring modulators.

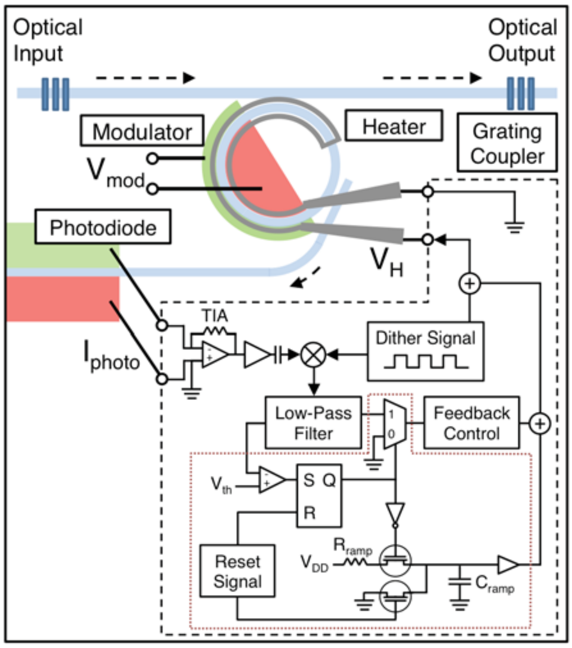

Fig. 2: The device used in this experiment (not to scale). The off-chip electronics interfacing with the integrated photonic elements are shown in the dashed box. Highlighted in red is the circuitry devoted to wavelength locking.

A promising solution that meets all of the aforementioned criteria lies in the technique of dithering the microring resonance to generate an asymmetric error signal centered at the microring resonance[5]. Fig. 1 illustrates the error signal and its correspondence with the microring resonance. Previously, we showed that this error signal, immune from fluctuations in power, could be used in conjunction with a feedback controller to thermally stabilize a passive microring resonator[5]. In this paper, we show that by adding additional electronic logic, the error signal can be utilized to establish the initial wavelength lock to the microring resonator. Additionally, we show that the technique can be adapted to a microring modulator, thereby validating its use for data applications.

The device, as is illustrated in Fig. 2, consists of a 15-μm radius depletion-mode silicon microring modulator. A thin film titanium-based heater is situated directly above the microring, separated from the microring by 1 μm of oxide. The drop port of the microring terminates in a defect-enhanced silicon photodiode, enabling the monitoring of the optical power dropped into the microring[6].

The off-chip electronics implementing the system are shown in the dashed box of Fig. 2. The electronics consist of low-speed (< 20-MHz bandwidth) analog & digital ICs. The dithering signal is applied thermally by applying a small 1-kHz square-wave voltage to the integrated heater. Our system was able to achieve wavelength locking with thermal dithering magnitudes as low as 0.04 K. It is desirable to operate with the smallest thermal dithering signal possible, as the thermal dithering will introduce noise into the optical signal.

The dashed red box of Fig. 2 indicates the additional electronic circuitry needed to implement the wavelength locking. The functionality of this circuitry is succinctly described in the state diagram of Fig. 3. A simple reset signal is used to trigger the voltage ramping on the integrated heater. As the microring is tuned to the laser wavelength the error signal will trip the system into the hold state, in which the feedback controller is activated and the microring is locked and stabilized against further drifts in temperature[5] or laser wavelength. Additional logic can easily be added to reset and re-attempt the wavelength locking should it fail on its initial attempt.

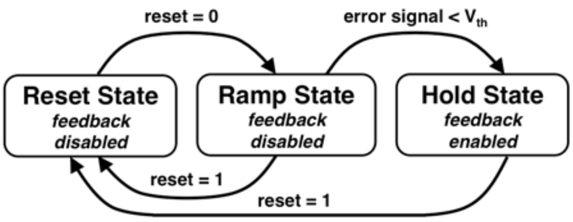

Fig. 3: A state diagram describing the functionality of the wavelength-locking circuitry (dashed red box, Fig. 2)

The wavelength scans in Fig. 4 demonstrate the system locking a passive microring resonator to a laser. Initially, the microring resonance is at ~1559.2 nm, and the laser is offset at ~1560 nm. Over the course of 50 s, the microring is tuned higher in wavelength until the system detects the error signal and establishes the lock. Fig. 4 shows that the locking is maintained up to 160 s (the limit of our data acquisition). To record the optical traces of Fig. 4, the ramp speed (rate at which the tuning occurs) of the system was drastically reduced, such that the wavelength locking would occur over the course of seconds. In subsequent trials, we increased the ramp speed to achieve wavelength locking in the ~ms time frame. In future implementations, the speed of the dithering signal can easily be increased to >1 MHz to allow the wavelength locking to occur in the ~μs time frame. At that point, the fundamental limits on the speed of the wavelength locking will be determined by the initial offset between the microring resonance and the laser wavelength, and the rate at which the integrated heater can tune the temperature of the resonator.

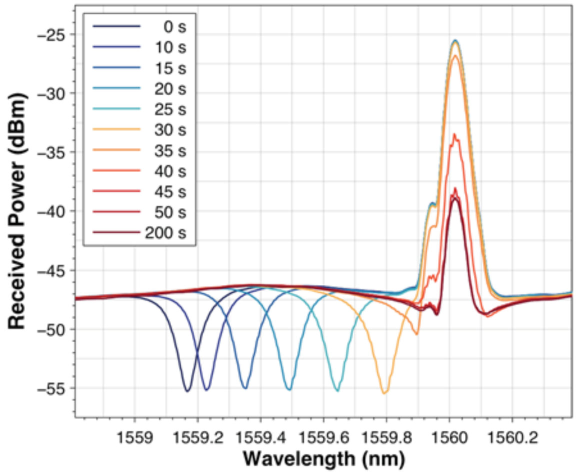

Fig. 4: Optical traces show the microring resonance being tuned and wavelength locked to a laser source.

While the reported results demonstrate the success of the technique when applied to a passive resonator, for the successful application of the technique for future silicon photonic interconnects it must be validated for data applications. Specifically, a critical concern is that the dithering of the resonance will impart a severe degradation on the optical data the microring resonator is generating or routing. To address this concern we adapt and demonstrate the technique for a microring modulator.

For a microring modulator, the resonance is not static, but rather oscillates between two resonance-states in order to imprint an electrical modulation onto an optical signal. The response that this system generates on a slow-photodetector is an average between the two resonance-states. Provided that the modulator is driven with a large enough voltage to produce a high extinction ratio, this broadened response will produce a desirable error signal, with the zero-crossing of the error signal corresponding to a microring-laser alignment producing optimum modulation. For the modulator used in this demonstration, this required a -5 V bias with 4-Vpp swing voltage, albeit desirable drive conditions will differ for the specific implemented modulator and will likely be considerably lower.

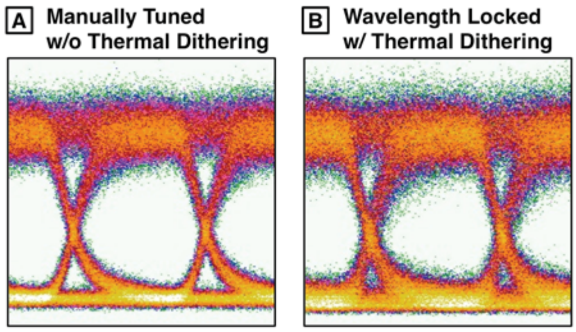

Fig. 5: A comparison between (a) manually tuning the integrated heater to achieve an optimum modulation and (b) using the wavelength locking system to tune the integrated heater automatically.

Akin to the wavelength locking depicted for a passive resonator in Fig. 4, our automated wavelength locking system was able to wavelength lock the microring modulator without required any additional modification. The eye diagrams of Fig. 5 depict the 5-Gb/s PRBS 2^{31}-1 optical signal generated from the microring modulator. Fig. 5(a) shows the modulation achieved when using the traditional method of manually tuning the integrated heater. In contrast, Fig. 5(b) depicts the modulation when the integrated heater is tuned automatically by our wavelength locking system. Remarkably, using the generated error signal, the wavelength locking system is able to tune the microring to a point that produces relatively the same modulation as when using manually tuning. This is a critical advantage of the error signal generated from the dithering technique. It should be noted that, as expected, the thermal dithering causes degradation to the generated data signal. In particularly, as seen in Fig. 5(b), the one and zero levels of the eye diagram are broadened from the dithering of the resonance.

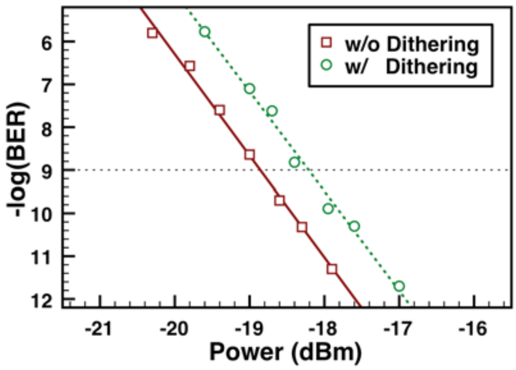

Fig. 6: BER measurements for the optical signals depicted in Fig. 5.

However, our BER measurements (Fig. 6) show that the generated optical data is still error-free (BER < 10^{-12}). Furthermore, the power penalty when implementing the system was measured to be only 0.7 dB, an encouraging metric for this proof-of-principle experiment. Part of this power penalty is intrinsic and attributable to the effect of the dithering signal on the one and zero levels. However, part of this power penalty is attributable to the electrical noise in our implemented circuitry, and can be reduced with proper implementation. Furthermore, additional circuit design can be used to reduce the magnitude of the thermal dither needed to lock, thereby lowering the intrinsic power penalty from the dithering signal and reducing the power penalty to a system tolerable value.

Conclusions

We have demonstrated an automated system for wavelength locking passive microring resonators as well as microring modulators. Our prior results[3,5] demonstrate that this system will also thermally stabilize the microring resonator/modulator. The demonstrated system is immune to optical power fluctuations, and the slow-speed analog and digital electronics comprising our implemented system have the potential to be directly integrated with the photonic components, providing a small-footprint, energy-efficient, WDM scalable method of wavelength locking and thermally stabilizing microring resonator based devices in their use in next-generation optical links.

Acknowledgements

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References

[1] J. E. Cunningham *et al.*, “Highly-efficient thermally tuned resonant optical filters,” Optics Express **18**(18), 19055-19063, 2010.

[2] E. Timurdogan *et al.*, “Automated Wavelength Recovery for Microring Resonators,” CLEO 2012.

[3] K. Padmaraju *et al.,* “Integrated Thermal Stabilization of a Microring Modulator,” OFC 2013, OM2H.7.

[4] W. A Zortman *et al.*, “Bit error rate monitoring for active wavelength control of silicon microphotonic resonator modulators,” IEEE Micro **33**(1), 42-52, 2013.

[5] K. Padmaraju *et al.,* “Microring Resonance Stabilization using Thermal Dithering,” IEEE Optical Interconnects 2013.

[6] D. F. Logan *et al.*, “Monitoring and Tuning Micro-Ring Properties Using Defect-Enhanced Silicon Photodiodes at 1550 nm,” IEEE Photon. Technol. Lett. **24**(4), 2011.