Microring Resonance Stabilization using Thermal Dithering

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Abstract— **We present the novel mechanism of thermal dithering for breaking the symmetry of a microring resonance, and experimentally show it can be utilized to thermally stabilize a silicon microring resonator experiencing fluctuations of 3 K.**

I. Introduction

Silicon photonics promises to deliver high-bandwidth energy-efficient optical communications to new frontiers in computing. The use of the silicon microring resonator is critical to achieving energy-efficient communications in a low-footprint package [1]. Microring resonators have a wavelength selectivity advantageous for wavelength-division-multiplexing (WDM). However, this same wavelength selectivity renders the microring susceptible to fabrication tolerences, and more importantly, temperature fluctuations.

For most applications, the minimum transmission point of the microring resonance is aligned with the laser wavelength it is routing or detecting. In this configuration, it is difficult to lock the microring resonance to the laser wavelength by measuring just the optical power transmission, because the direction of the resonance drift is ambiguous in relation to the transmission of optical power. Previous work has demonstrated resonance locking by algorithmically searching for the minimum transmission point in a microring resonance [2]. Here, we introduce the use of thermal dithering to break the symmetry of the microring resonance.

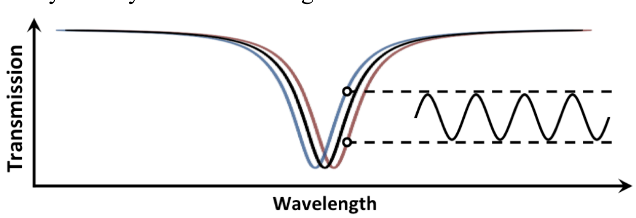

Fig. 1: A small dither signal, applied thermally to the microring resonator, results in a small modulation of the optical signal.

Fig. 1 illustrates thermal dithering, whereby a small modulation is applied to the local temperature of the microring in order to produce a small modulation of the optical signal. The generated optical modulation will either be in-, or out-of-phase with the driving signal, depending on which side of the resonance the laser wavelength is positioned. By mixing the modulated optical signal with the driving dithering signal this information can be recovered as shown in eq. (1), where f_D is the frequency of the dithering signal, and ϕ is the relative phase (0 or π) of the modulated optical signal.

$$\cos(f_D t) \otimes \cos(f_D t + \phi) = \frac{1}{2}[\cos(2 f_D t + \phi) + \cos(\phi)] \qquad (1)$$

The higher harmonic can be filtered, leaving the sign of the DC component {cos(ϕ) term} as an indication of the location of the resonance relative to the optical signal.

II. Device & Experimental Setup

As illustrated in Fig. 2, the device consists of a 15-µm radius silicon microring with grating couplers for the optical input and output. 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 [3].

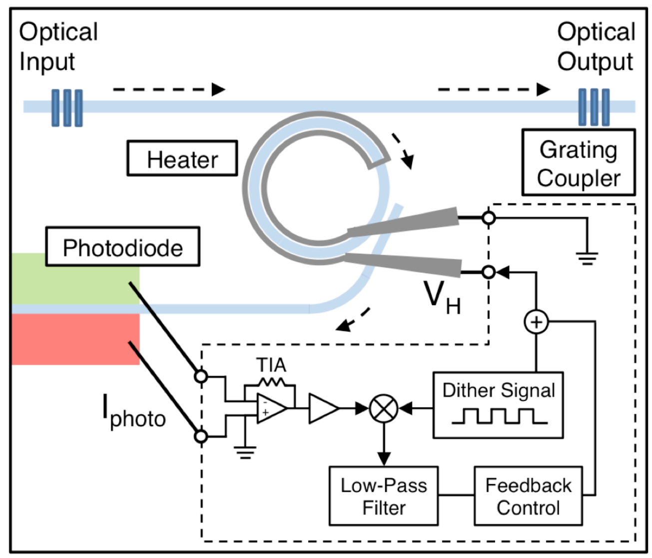

Fig. 2: The device used in this experiment (not to scale). The off-chip electronics interfacing with the integrated photonic elements are shown in the dashed box.

The off-chip electronics implementing the thermal dithering system are shown in the dashed box of Fig. 2. The electronics consist of low-speed (< 20-MHz bandwidth) analog ICs. A 1-kHz square-wave is used for the dithering signal, as a square waveform is easier to synthesize electronically than a sinusoidal waveform, and results in a larger DC component when mixed. The dithering signal is chosen to be higher in frequency than the thermal fluctuations it is monitoring.

The optical signal, modulated by the thermal dithering, generates a photocurrent on the integrated silicon photodiode. The photocurrent is converted to a voltage using a transimpedance amplifier (TIA), and then furthered amplified. An analog mixer IC (AD 633) is used to then mix the amplified signal with the driving dithering signal. A low-pass RC filter is used to suppress the AC component of the mixed product. A proportional-integral-derivative (PID) feedback controller then uses the processed signal as an error signal to determine the drift of the microring and apply an appropriate correction to the heater [4].

III. Experimental Results

The use of the thermal dithering signal has the consequence of reducing the extinction ratio of the microring resonance. In Fig. 3, the simulated and measured resonances of the microring resonator (Q of ~14,000) are plotted for square-wave thermal dithering signals of magnitude 0.1 K and 0.2 K. A larger thermal dither will result in a larger reduction of the extinction ratio. For thermal dithering of magnitude 0.1 K and 0.2 K the reduction in extinction ratio was measured to be 1.9 dB & 4.8 dB, respectively. Simulations produced identical results (Fig. 3).

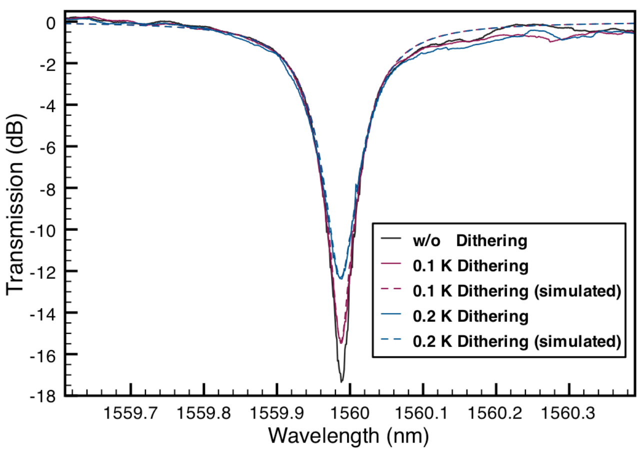

Fig. 3: The microring resonance as it is subjected to thermal dithering signals of varying magnitude (simulations in dashed).

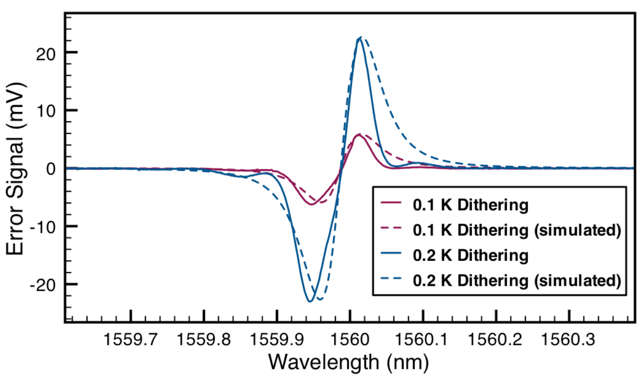

Fig. 4: The generated electrical response (for use as the error signal) for thermal dithering signals of varying magnitude (simulations in dashed).

While a larger thermal dither results in a larger reduction in extinction ratio, it has the advantage of producing a stronger error signal. Fig. 4 plots the simulated and measured waveforms of the error signal generated from mixing the dithering signal with the generated signal, and then subsequently filtering to the DC component (as shown schematically in Fig. 2).

The error signal generated in Fig. 4 is valuable because it breaks the symmetry of the microring resonance. The polarity of the response clearly distinguishes between the red and blue sides of the microring resonance. Furthermore, the zero point of the monotonic slope is located at the resonance point of minimum transmission. Hence, a feedback system can easily stay locked to the zero point in order to match the laser wavelength with the microring resonance.

While a larger error signal makes the system more robust against noise, we found that a 0.1 K dithering signal was sufficient for maintaining laser locking to the microring resonance. The thermal dithering system was cascaded with a feedback system (as schematized in Fig. 2) to thermally stabilize the microring resonator. To test the system, 10-Hz sinusoidal thermal fluctuations of magnitude 3 K were generated using an external visible laser [4].

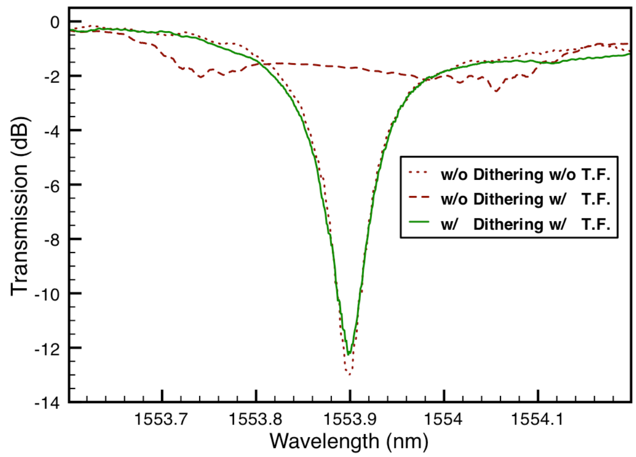

Fig. 5: The microring resonance when subjected to thermal fluctuations (T.F.), with and without the dithering & feedback system implemented.

In order to verify the thermal stabilization, wavelength scans were performed of a resonance adjacent in wavelength to the resonance that the thermal dithering & feedback system was locked to (Fig. 5). As Fig. 5 shows, with the thermal dithering & feedback system implemented, the microring resonance stays locked to the laser wavelength, with the dynamic tuning of the heater counteracting the thermal fluctuations inflicted on the microring.

The demonstrated system is able to stabilize the microring resonance amidst thermal fluctuations, conceivably up to the tuning range of the heater. The use of thermal dithering to generate the error signal has the advantage of giving the feedback system immunity to power fluctuations (the zero crossing of the error signal will stay constant). This renders the system robust against fluctuations in the received power, and immune to fabry-perot artifacts in the optical path. The use of low-speed analog ICs in the experimental implementation lends credibility to the system's ability to scale in an energy-efficient manner to the multiple microring resonators that comprise a WDM photonic interconnect.

References

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