Automated Wavelength Recovery for Microring Resonators

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Abstract: We lock an adiabatic microring resonator to a laser line with a lock-in time of 200μs using a digital control loop, thereby experimentally demonstrating the first automated and scalable wavelength recovery approach for microring resonators.

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1. Introduction

Silicon photonics is poised to meet the increasing demand for high-bandwidth, low-power, and densely-integrated optical communications in CMOS-compatible environment. Microring resonators in particular have become ubiquitous photonic building blocks that have already been utilized to demonstrate modulators, filters and switches [1,2]. However, the large frequency dependence with geometry (~100GHz/nm) and thermo-optic coefficient (~10GHz/°C) innate to silicon microrings threaten to preclude their use in dense wavelength division multiplexed (DWDM) applications where the channel spacings are tight and temperatures may vary by as much as 15°C [3]. Several promising solutions to address this challenge have come in the form of low-power (4.4μW/GHz) and high-speed thermal tuning [4], sensor-based thermal compensation [5], and athermal devices [6]. However, while temperature sensor [5] and athermal [6] solutions address the thermal stability issue, they do not address fabrication based frequency variations. A recent study has leveraged scattering of the microring filters for wavelength locking [7], however, scattered light based techniques are not of sufficient reliability to enable large-scale implementations

In this work, we experimentally demonstrate the first high-speed and scalable on-chip optical wavelength recovery capable of compensating both fabrication and thermal induced frequency variations in on a silicon photonic chip. Using a thermally-tunable adiabatic resonant microring (ARM) resonator [4], combined with a unique wavelength recovery algorithm implemented using an FPGA, we demonstrate low-power (less than 1mW for $\pm 10^{0}$C) and high-speed (as low as 200 μs) wavelength recovery. Furthermore, this approach is capable of being implemented using advanced CMOS electronics, hybrid or monolithically integrated with silicon photonics.

2. Experiments and results

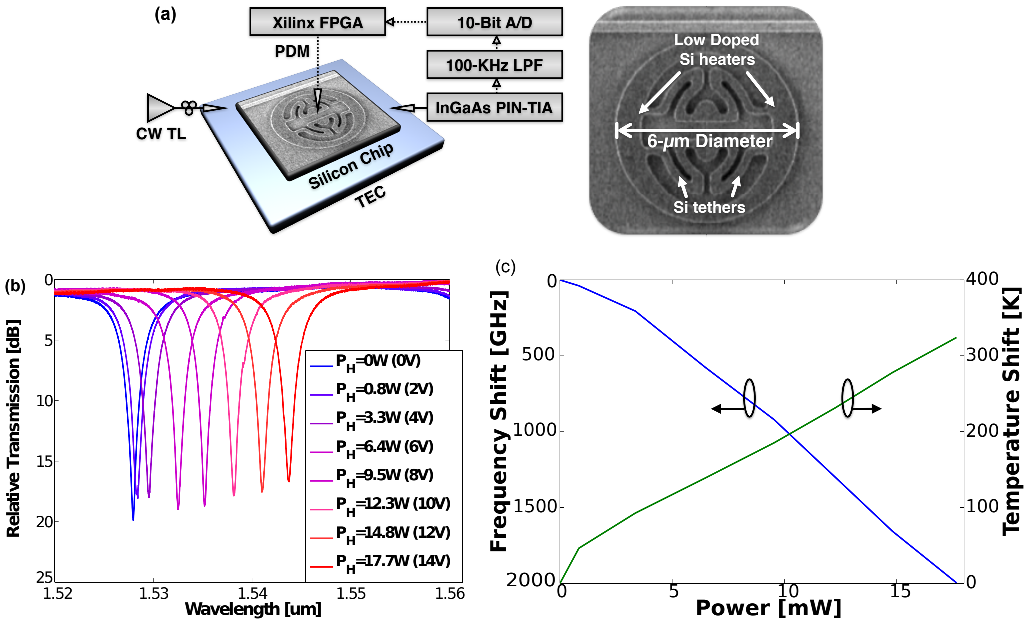

Figure 1 – (a) diagram of experimental setup for wavelength recovery using an ARM resonator (left), and top-view scanning electron microscope (SEM) image of the device (right) (b) measured spectrum as a function of heater electrical power (red shift is indicated y coloring from blue to red), (c) measured frequency shift and calibrated temperature shift as a function of heater power.

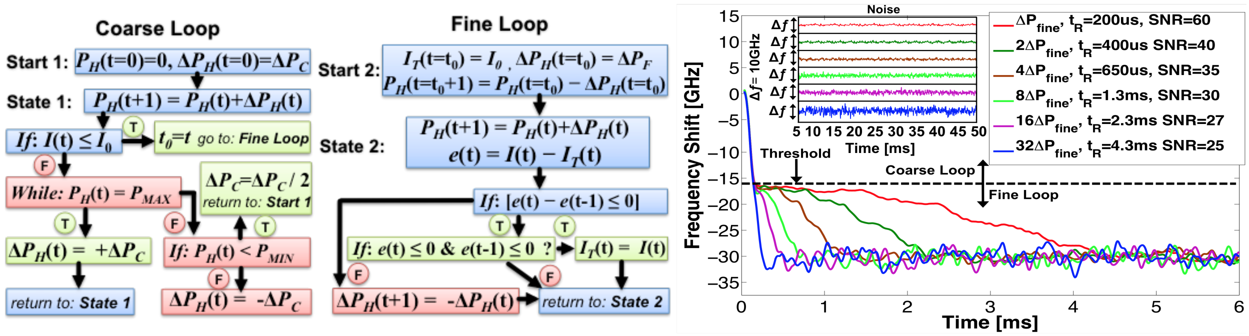

Figure 2 - Coarse and fine loop flow charts for wavelength recovery decision-making for thru port (left) where **P_H(t)** is real-time power dissipated in the heater, **ΔP_H(t)** is real-time power variation in the heater, **$P_{MAX/MIN}$** is maximum/minimum heater power, **$\Delta P_{C/F}$** is coarse/fine minimum power variation in the heater, **I(t)** is real time output intensity, **I_0** is the threshold intensity, **e(t)** is the error signal and **I_T(t)** is the target intensity which is constantly updating for global minima locking. Drop port decision-making algorithm can be implemented by changing comparison statetements and using the rest of the algorithm. Microring wavelength recovery results as a function of increasing minimum power variation in the heater (right) and stability of the recovered signal is investigated as a function of loop speed (right-inset).

The device discussed in this work, shown in Fig. 1a, is an ARM resonator filter with 6μm diameter, fabricated with integrated heaters formed by resistive low-doped Si regions within the adiabatic microring [4]. The resonance of the device is tuned by applying a voltage bias across the integrated heaters, The spectra for various voltage and power levels have been measured using a tunable laser as shown in Fig. 1b. Frequency shifts of 1 THz and 2 THz are achieved for 8.5mW and 17mW dissipated power, respectively. A thermoelectric cooler (TEC) is placed under the chip, and coupled to a thermistor for calibrating the integrated heater power to temperature shifts and the calibrated data is shown in Fig. 1c. Temperature shifts of 150^0K and 300^0K correspond to 8.5mW and 17mW heater power, respectively.

The experimental setup used for wavelength recovery is shown in Fig. 1a. The through port intensity is detected by a transimpedance amplifier (TIA) and low pass filtered with a cut-off frequency of 100KHz. A 10-bit analog-to-digital converter (A/D) at 100KSa/s is used to digitize the output of the filter. An FPGA receives the digital signal after the A/D block and makes a decision. Based on the decision, a pulse-density-modulated (PDM) signal with a 10-bit resolution is fed back to tune the power of the integrated heater.

The decision-making control algorithm for wavelength recovery is designed for continuous search of the minimum (for the thru port) or maximum (for the drop port) level. The automated feedback algorithm works with no information about the on/off resonance levels, quality factor and the frequency offset. The algorithm, depicted in the state diagram in Fig. 2a, consists of two loops. A coarse loop is implemented for fast localization of the optical resonance around the laser frequency, by comparing the threshold intensity. By appropriately selecting the threshold intensity, off resonance Fabry-Perot cavities and local minima are eliminated. When the coarse loop localizes the laser frequency, a fine loop intervenes to continuously search for global minima (for the thru port) and/or maxima (for the drop port). Since the target level is never known by the algorithm, the feedback control loop is not proportional to the error signal. Therefore, an increase of the minimum power change in the heater will lead to a tradeoff between faster wavelength recovery and increased overshoot at steady state. In order to validate this point, the minimum change of the power in the heater is multiplied by 1, 2, 4, 8, 16, 32 for each individual experiment while coarse loop settings are kept constant and CW laser is fixed to 1528.23nm (30GHz offset). Wavelength recovery results are shown in Fig. 3b. Recovery time is diminished from 4.3ms to 200μs and signal to noise ratio (SNR) is decreased from 60 to 20.

3. Conclusions

We demonstrate experimentally lock an ARM resonator to CW laser line with a settling time of 200μs using a digital feedback loop. This is the first demonstration of automated, scalable and CMOS compatible wavelength recovery approach for microring resonators. In future work, the speed of the feedback loop will be further increased, and a full optical link that includes a large number of modulators and filters will be demonstrated.

4. References

[1] Q. Xu, B. Schmidth, S. Pradhan and M.Lipson, " Micrometre-scale silicon electro-optic modulator," *Nature* 435, 325-327 (2005).
[2] M. R. Watts et al. , "Vertical junction silicon microdisk modulators and switches", *Opt. Expr.* pp. 21989-22003 (2011).
[3] M. W. Riley, J. D. Warnock and D.F. Wendel, "Cell Broadband Engine Processor: Design and Implementation," *IBM J. Res. & Dev.* Vol. 51 No. 5 (2007).
[4] M. R.Watts et al., "Adiabatic Resonant Microrings (ARMs) with directly integrated Thermal Microphotonics," *CLEO,* Baltimore, (2009) .
[5] C. T. DeRose et al. "Silicon Microring Modulator with Integrated Heater and Temperature Sensor for Thermal Control, " *CLEO*, San Jose (2010).
[6] B. Guha, B. B. C. Kyotoku and M. Lipson, "CMOS-compatible athermal silicon microring resonators," *Opt. Expr.* 3487 (2010).
[7] C.Qiu, "Wavelength tracking with thermally controlled silicon resonators," *Opt. Expr.* 5143 (2011).