Thermal stabilization of a microring resonator using bandgap temperature sensor

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***Abstract*— We demonstrate a thermal stabilization method for a microring modulator by measuring the absolute temperature of the ring and surrounding areas using two pairs of matched p-n junctions. Stabilization is accomplished without needing optical power.**

I. INTRODUCTION

Microring resonator devices are seen as promising components for use in future silicon photonic enabled optical interconnects. Due to their resonance based operation, microrings offer intrinsic advantages such as small footprint, power efficiency, and wavelength division multiplexing (WDM) capability. However, the resonance also enhances the ring's sensitivity to environmental temperature fluctuations [1]. Overcoming this thermal sensitivity is necessary for commercial adaptation of microring devices.

Many researchers have worked on methods to compensate for microring thermal sensitivity. These projects have focused on (1) reducing the temperature sensitivity of the resonant structures using athermal materials, and (2) using integrated heaters combined with active feedback circuitry [1]. While successful, both of these approaches have drawbacks. The athermalzing approach uses novel materials to counteract the thermal optic coefficient of silicon, and requires additional manufacturing steps. While all existing active feedback approaches depends on the detection of optical power, which increases system cost due to the need for photodetectors, and requires optical power to function.

We present an active stabilization system based on measuring the absolute temperature of the microring using an integrated bandgap temperature sensor. Our approach extends earlier efforts to measure temperature on-chip [2] and does not require the presence of optical power to function. This type of control system has the potential to reduce cost and power consumption of microring based optical systems.

II. DEVCIE DESIGN

The microring device used in this study was fabricated at the A*STAR Institute of Microelectronics (IME) via an OpSIS multi-project-wafer run [3]. The process uses an 8" Silicon-on-Insulator (SOI) wafer from SOITEC with 220 nm top silicon layer and 2 µm bottom oxide. The device is a modification of existing microring modulator designs demonstrated in the OpSIS platform and does not require process modifications. It contains a high-speed modulation p-i-n junction, a resistive integrated heater, and two matched narrow p-n junctions for temperature sensing (Fig. 1a).

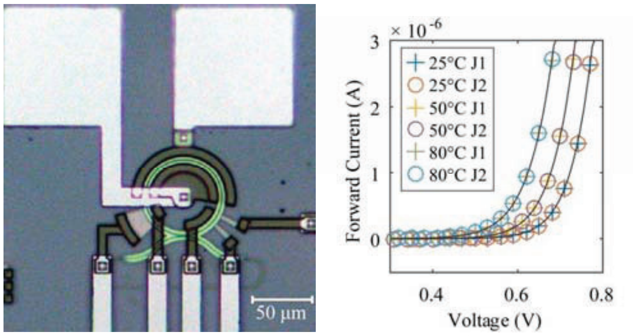

Fig. 1(a) Fabricated microring modulator viewed through a microscope. The matched p-n junctions used for temperature sensing are on the lower right quadrant of the device, while the integrated heater is in the lower left. The high-speed modulation junction covers the top semicircle. (b) IV curves of the two junctions under different temperatures. The junctions match perfectly.

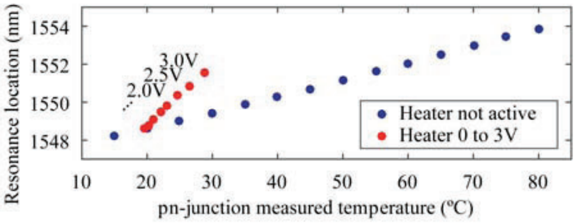

Fig. 2 Microring resonance location vs. temperature measured by the p-n junctions. The p-n junctions accurately measures the microring temperature when the integrated heater is not active (bottom blue). However, when the integrated heater is used to heat up the ring while the global temperature is held constant (as an example, at 20 ºC for the top red curve), the relationship between measured temperature and resonance location is skewed.

Temperature measurement can be performed by forward biasing the matched p-n junctions at different currents then measuring the difference in forward voltages [4]. Due to the matching of the junctions (Fig. 1b) the voltage difference is linearly correlated to the absolute temperature of the junction. We measured the temperature of the microring by biasing one junction at 1 µA and the other at 10 µA. The temperature thus measured shows excellent agreement with optically measured ring resonance location (Fig. 2). However, an interesting problem occurred when the integrated heater was used to heat the microring. The red curve in Fig. 2 shows the p-n junctions measuring a lower temperature than the true temperature of the microring when heater power was applied. We suspect that a thermal gradient builds up around the integrated heater, causing the microring to experience an aggregate temperature change greater than that measured at the junction.

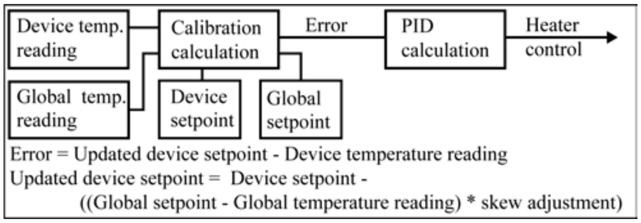

Fig. 3 Block diagram of the feedback controller used in the experiment. Device temperature is the reading from the sensor in the ring, and global temperature is the reading from the second sensor. The two setpoints are constants, and the skew adjustment factor is found using slopes interpreted from Fig. 2. The measured change in global temperature is used to update the target temperature for the feedback, which acts using the ring sensor reading.

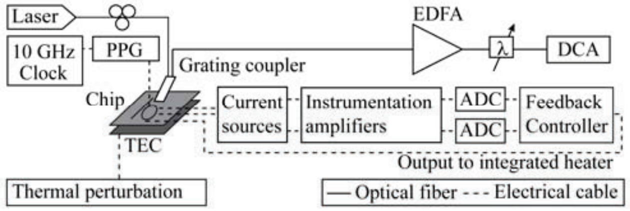

Fig. 4 Experimental setup to demonstrate temperature stabilization.

III. FEEDBACK SYSTEM DESIGN

Due to the skewed temperature reading from the p-n junctions, a traditional proportional-integral-derivative (PID) feedback controller will not be able to stabilize the microring using the integrated heater. Any change in the environmental temperature would cause the PID controller to overreact and change the resonance too much. What is needed is a way to calibrate for the effect of integrated heater on the sensor.

We accomplished this calibration by using a second pair of matched p-n junctions on the chip located 300 µm away from the microring. This second sensor is close enough to the ring to be similarly affected by global temperature changes, but remains far enough away to not be affected by the integrated heater. Combining this secondary information with the skewed but still useful reading from the original pair of p-n junctions, the PID controller can close the loop to stabilize the microring. Fig. 3 shows a block diagram of the feedback controller and the calibration algorithm.

IV. RESULTS

Fig 4. shows the experimental setup of the experiment. The chip containing the microring modulator was attached to a thermal-electric-cooler (TEC) using thermal adhesive. The global temperature of the TEC can be modified at ~0.3 K/s with a driving current of 1 A. A laser was coupled into the device using a grating coupler, and low speed probes were used to contact the p-n junctions and integrated heater. 10 GB/s data modulation was achieved using RF probes with a reverse bias of -2.8 V and a 5.5 Vpp driving signal.

The pairs of p-n junctions were forward biased using LM234Z programmable current sources, and the output voltages were amplified using INA116PA instrumentation amplifiers. The feedback controller and calibration calculation were performed using a PIC24H microcontroller, which has built-in 16-bit analog-to-digital converters (ADC) and 10-bit digital-to-analog converters (DAC). The feedback system ran at a sampling rate of 80 Hz and consumed a maximum power of 7 mW, without counting the dissipated heater power.

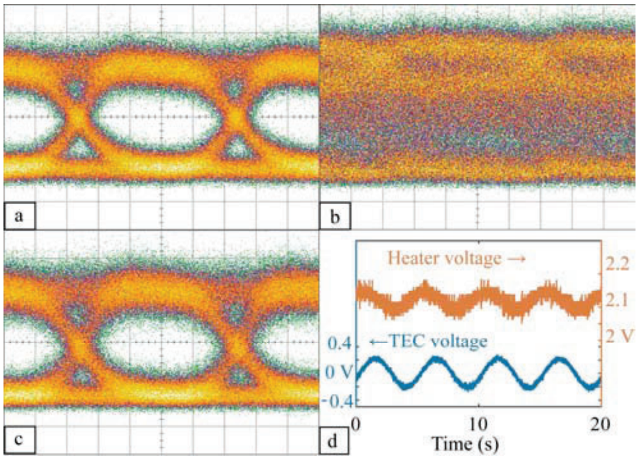

Fig. 5 (a) 10 Gb/s eye diagram without thermal perturbation, (b) with thermal perturbation but without stabilization, and (c) with thermal perturbation and with thermal stabilization enabled. (d) Heater voltage during feedback control (top red curve). There is a ~1 second delay for the TEC temperature change (bottom blue curve) to propagate to the microring.

Fig. 5d shows the feedback system in action against a thermal shift of 1.0 K. The bottom curve is the control voltage of the TEC, where a positive voltage is an increase in temperature and negative a decrease. The top curve shows the heater voltage generated by the feedback controller. Using the calibration routine the feedback system was able to correctly compensate for the temperature perturbation. Eye diagrams with and without the active thermal feedback are shown in Fig. 5a-c, demonstrating successful thermal stabilization.

V. CONCLUSION

In this paper we present a novel device that integrates matched p-n junctions to measure the absolute temperature of a microring. The proximity of the sensor to the integrated heater results in skewed readings, but we were able to overcome this limitation by using an additional pairs of sensors in the feedback system design. This experiment show the potential of temperature measurement based feedback systems for microring thermal stabilization. These feedback systems do not need optical power to function, and provide a potentially low-cost and energy-efficient way to solve the thermal sensitivity challenges of microring resonator devices.

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