Wavelength Locking of Multicast Signals using Photo-Conductive Effect in Silicon Photonic Platform

Alexander Gazman, Ziyi Zhu, Meisam Bahadori, and Keren Bergman

Department of Electrical Engineering, Columbia University, New York, NY 10027, USA

***Abstract*— We develop an automated wavelength locking of microring resonators for routing optical signals in unicast and multicast modes. The locking algorithm utilizes the photo-conductive effect of the integrated microheaters for tapless monitoring of the optical power coupled to the microring.**

I. Introduction

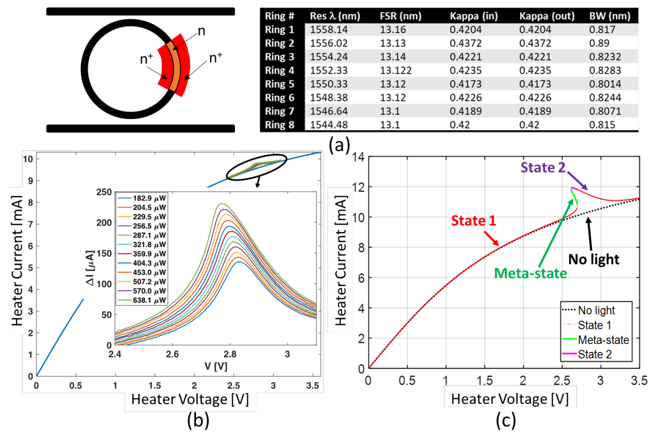
MICRORING resonators (MRRs) are one of the most versatile building blocks in the silicon photonic (SiP) technology. Their small footprint, low power consumption and wavelength tunability has made them attractive in optical network applications. Functionalities such as optical modulators, filters for wavelength-devision-multiplexed signals [1], and cavity elements in laser structures have been demonstrated successfully. However, due to their resonant nature and the high thermo-optic coefficient in silicon, changes in local temperature will shift the resonance of the MRR from the desired operation [2]. The shift in the resonance can reduce the extinction ratio in modulators, lower received power, introduce crosstalk in filters [3], and shift lasing wavelength in cavity structures.

To address the thermal sensitivity problem, active feedback loops based on tapping a portion of the optical signal with integrated photodiodes (PD) or measuring the local temperature with integrated diodes and correcting the resonance location with integrated heaters have been proposed. The main drawbacks of these solutions are the increased optical power budget, footprint area, and additional I/O ports in 2D integration.

Recently, the use of doped-resistive heaters as a controller for the local temperature of the MRR and to monitor the coupled optical power through the photo-conductive (PC) effect has been shown [5]. This approach eliminates the need for additional components for tapping the optical power on the SiP chip, hence paving the way for reliable and scalable SiP designs based on MRRs. In this work, We present an algorithm that utilizes the PC effect for tuning/locking a single MRR for a unicast transmission and simultaneously several MRRs for higher order multicast functionalities. The device used in the experiments is a 1x8 array of MRRs [4] each equipped with a n^{++}–n–n^{++} doped heater configuration.

II. Photoconductive effect

A micro-heater can be directly integrated into an MRR by doping parts of the ring and creating n^{++}–n–n^{++} configuration. This is shown in Fig. 1a along with the parameters of all the eight rings of our SiP device. The resonances of the cascaded MRRs [4] are 2 nm apart, the FSR of each ring is



Ring #	Res λ (nm)	FSR (nm)	Kappa (in)	Kappa (out)	BW (nm)
Ring 1	1558.14	13.16	0.4204	0.4204	0.817
Ring 2	1556.02	13.13	0.4372	0.4372	0.89
Ring 3	1554.24	13.14	0.4221	0.4221	0.8232
Ring 4	1552.33	13.122	0.4235	0.4235	0.8283
Ring 5	1550.33	13.12	0.4173	0.4173	0.8014
Ring 6	1548.38	13.12	0.4226	0.4226	0.8244
Ring 7	1546.64	13.1	0.4189	0.4189	0.8071
Ring 8	1544.48	13.1	0.42	0.42	0.815

Fig. 1. (a) Structure of the MRR with doped heater. (b) Measured I-V of the heater with various optical powers. (c) Simulated I-V response of the heater showing the bi-stability phenomenon.

close to 13.13 nm and their 3dB optical bandwidth is close to 0.82 nm. The input and drop power couplings are about 17% ($\kappa \approx 0.42$). The I-V curve of this microheater follows the model $I_H = V_H/R_0 \times 2/(1+\sqrt{1+K_v V_H^2})$ where R_0 is the linear resistivity and K_v is related to the self-heating of the resistor [2]. The measured I-V curve of one of the MRRs in our experiment is shown in Fig. 1b which fits to this model for R_0 = 170 Ω and K_v = 0.6 V^{-2}. As the heat generated by the ohmic heater aligns the resonance with the wavelength of the laser, the optical power inside the MRR is boosted. The absorption of the light inside the ring will generate extra electrons and holes that contribute a change in the ohmic conductance. This photo-conductive effect is observed in Fig. 1b as the slight overshoots in the current when the laser is ON and the voltage of the heater is near 3V. The inner plot of Fig. 1b shows experimental results of the PC effect, where increased optical power coupled to the MRR causes the resistance of the integrated doped-heater to reduce, hence increasing the change in the bias current.

To take the PC effect into account, the I-V curve model should be modified with new parameters $R_0' = R_0/(1+K_pP)$ and $K_v' = K_v(1+K_pP)$ where P is the optical power inside the ring, and K_p describes the generation of electrons and holes. Figure 1c shows a simulation of our device when the input laser power is 1 mW and K_p = 0.005 mW^{-1} indicating the existence of a bi-stability cycle with an artificial meta-state [6].

III. Experimental setup

The experimental setup is shown if Fig 2(a). A Tunable laser (TL) is used to provide channel wavelength. Pseudo

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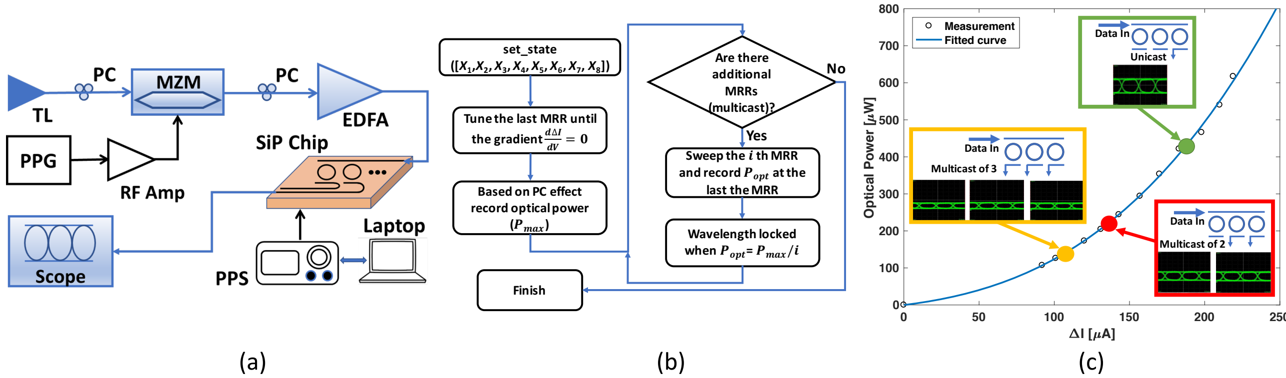

Fig. 2. (a) Experimental setup demonstrating MRR locking using PC effect. (b) Locking algorithm for user defined multicast operation. (c) PC response. The inner eye-diagrams represent locked 10 Gb/s signals in unicast (green), multicast of 2 (red) and multicast of 3 (orange).

random bit sequence (PRBS) is generated using a programmable pulse generator (PPG). A 10 Gb/s PRBS data is amplified, and used to modulate optical signal via a Mach-Zehnder Modulator (MZM). Two polarization controllers (PC) set maximum transmission before and after the MZM. A constant gain erbium doped fiber amplifier (EDFA) is used to overcome fiber to grating coupler loss in the SiP Chip. A Laptop is used to program the Precision Power Supply (PSS) to measure the I-V response of the MRR, and to perform the locking algorithm. The output drop ports of the MRRs are directed to a scope for optical power measurement and eye-diagram analysis.

IV. Unicast/Multicast Locking Algorithm

The locking algorithm based on PC is outlined in the flowchart of Fig. 2(b). The user sets the desired multicast configuration by the command *set_state([X_1,X_2,X_3,X_4,X_5,X_6,X_7,X_8])* where X_i = '1' represents signal drop by the i^{th} MRR and X_i = '0' represents the state in which the i^{th} MRR is not participating in the multicast operation.

For example, in the command *set_state([1,1,1,0,0,0,0,0])*, the locking algorithm will configure the MRRs to multicast the incoming data to ports 1, 2 and 3. The algorithm first locates the last participating MRR in the cascaded structure, 3rd MRR in the example, and locks it to maximum power in its drop port. This step is done by increasing the bias voltage on the doped heater, and monitoring the ΔI (= $I_{H+PC} - I_H$) until the gradient equals to zero. The I-V curve at no-applied light (blue curve in Fig. 1b) and the ΔI curves for different optical powers (inset of Fig. 1b) are stored as look-up tables. In each tuning step, ΔI is calculated by taking the difference of the measured current at operation and static case (no optical signal). Since the peak of each ΔI curve in the inset of Fig. 1b corresponds to the locked state of the ring, these peaks were combined and interpolated to create the curve in Fig. 2(c). At the end of the tuning process, the resonance of the 3rd MRR is locked to the laser wavelength, the value of the absolute power inside the bus waveguide is calculated from Fig. 2(c) by measuring ΔI. This state corresponds to the green circle on Fig. 2(c). At this state, 100% of the laser power is dropped by the 3rd MRR.

Next, the algorithm checks if there are additional MRRs chosen by the user for multicasting. If yes, the second from last starts the tuning process (MRR2 in this example) but we keep monitoring the ΔI of the last MRR until its corresponding power is reduced to half (3dB). In this state, both MMR3 and MMR2 are guaranteed to split the power equally (red circle on Fig. 2c). Finally, the tuning procedure is performed on MMR1 until the monitored ΔI of MMR3 corresponds to 33% of its original power. In this state, all the three MRRs are configured to drop 33% of the laser power and multicast operation is set. This corresponds to the orange circle on Fig. 2(c). Error-free operation and open eye diagrams were confirmed and captured in each step of the tuning procedure as shown on Fig. 2(c). The equal openness of the eyes indicates that the optical power is indeed divided equally between the MRRs in each step of the tuning procedure.

V. Conclusions

By characterizing the observed photo-conductive response of the integrated doped microheaters in microring resonators, we developed a locking algorithm for tapless operation of optical multicast in an 1x8 array of MRRs in silicon photonics. It was demonstrated that not only the photo-conductive effect can be used to lock the resonance of MRRs to the laser wavelength, it can also be utilized to set the drop optical power to any fraction of its maximum value.

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