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Electronic Control and Stabilization of Silicon Photonic Microring Resonator Circuits

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In silicon microring-based circuits with many resonators, in-resonator photoconductive heaters (IRPHs) provide a means for automatic tuning and stabilization by allowing for both monitoring and tuning the resonance conditions of individual resonators. Using IRPHs, automatic tuning of a doped-silicon series-coupled four-ring Vernier filter is demonstrated.

The unwanted spectral shifts in silicon microring-based systems, due to temperature and fabrication variations [1], can be mitigated by implementing automatic tuning and stabilization techniques. This can be achieved using feedback loops, which require sensing of the resonance conditions and tuning the resonators until the desired resonance conditions are met. Typically, while the sensing operation can be accomplished using various detection methods, separate electro-optic or thermo-optic tuners are required for tuning [1-3]. However, using separate elements for the sensing and tuning operations does not scale well to systems with large numbers of rings, due to the increase in footprint, number of electrical contacts, and fabrication cost. In some cases (e.g., series-coupled resonators), the resonance conditions of all of the resonators in a system cannot be readily determined from the system's outputs alone. Such instances may require multi-dimensional optimization algorithms [3], which could increase the time required to reach the desired resonance conditions.

In-resonator photoconductive heaters (IRPHs) can provide a solution. IRPHs are doped resistive heaters integrated into silicon optical resonators. IRPHs have photodetection capabilities, due to defect-state-absorption, and show high responsivities [4]. Using IRPHs, we demonstrated automatic tuning and stabilization of one-ring and two-ring filters [4] as well as the tuning of a two-ring Vernier filter to all of the ITU channels (200 GHz spacing) in the C-band [5]. In [6], we demonstrated a thermally tunable four-ring Vernier filter with attractive spectral features for WDM applications. In [4], we showed that IRPHs can be used to automatically find the desired filter response of a series-coupled filter by tuning the resonators sequentially, starting with the resonator coupled to the input-bus. We tune each resonator by maximizing the photocurrent measured by the resonator's IRPH. Importantly, this algorithm scales linearly with the number of series-coupled resonators. In this paper, we use this method to automatically tune a four-ring Vernier filter.

A micrograph of a fabricated series-coupled four-ring Vernier filter is shown in Fig. 1(a). The silicon rib waveguides (rib height = 220 nm, slab height = 90 nm) in the resonators were *n*-doped to form the IRPHs. These IRPHs are shown as resistors in Fig. 1(a). Here, the different path lengths of the rings set the free spectral range (FSR) of the device (37.21 nm) to be wider than the C-band. Since the IRPHs carry both heater-currents and photocurrents, a calibration step was first performed to measure the heater-currents with the laser input turned off. Fig. 1(b) shows the photocurrents measured after setting the laser input to an ITU wavelength of 1536.61 nm and sweeping the power applied to the IRPHs in Rings 1-4 (sequentially). Here, the photocurrent of each IRPH was calculated by subtracting the pre-calibrated heater-current from the total measured current [4]. At the end of each sweep, the voltage of the corresponding IRPH was set to the value that maximized its photocurrent. For illustration purposes, here we have chosen to sweep the heater powers. However, in practice, a simple maximum search algorithm can be used to find the maximum photocurrents [4]. A further optimization step was applied after each sweep to adjust for any shifts in the resonances of the previously tuned rings due to thermal crosstalk. The through- and drop-port spectra after completing the tuning and the optimization steps are shown in Figs. 1(c) and (d).

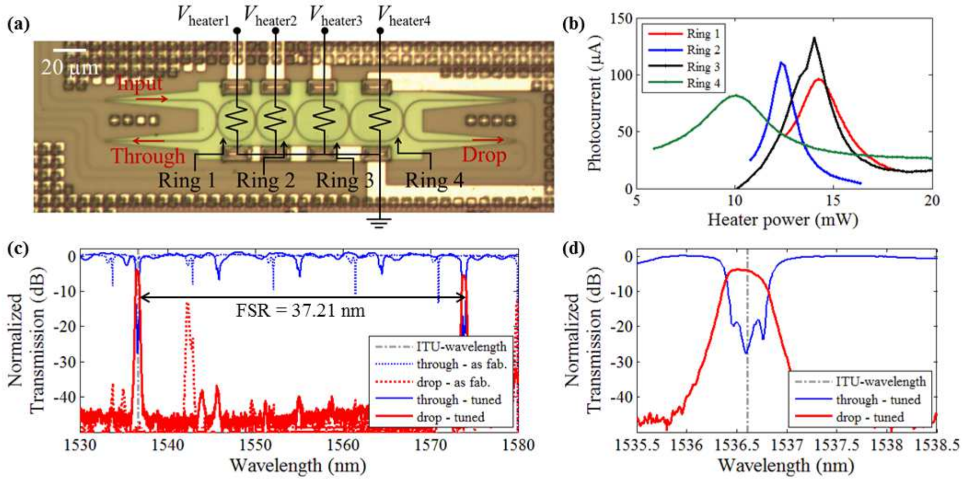

Fig. 1. (a) Micrograph of a fabricated silicon four-ring Vernier filter. (b) Photocurrents measured in the IRPHs during the tuning process. (c) Normalized through- and drop-port spectra as fabricated and after automatically tuning filter to ITU channel at 1536.61 nm. (d) Zoomed-in spectra near the ITU wavelength after tuning.

In summary, we have demonstrated automatic tuning of a four-ring series-coupled Vernier filter. The tuning was achieved without compromising the area or cost efficiency of the device and using methods that scale linearly with the number of series-coupled resonators. Our results suggest that IRPHs can be used for automatic tuning and stabilization of silicon photonic microring-based circuits with many resonators.

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