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On-Chip High-Order Frequency Filter with Fabrication Error Recovery

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Abstract: We demonstrate a high-order frequency filter based on microring pairs, capable of restoring distorted transmission functions by dynamically adjusting resonance parameters. Individual rings are thermo-optically tunable and are adjusted based on an evolutionary algorithm.
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Compact optical filtering systems, based on cascaded resonating devices, have been shown to provide critical functionalities on chip [1,2]. The performance of these devices, however, critically depends on the various dimensions of the design. Unfortunately, fabrication at this scale is prone to considerable deviation. In a simple filter, one could perhaps restore some of the performance of the device using tuning mechanisms to compensate for fabrication errors [3,4]. However, in complex filters composed of large numbers of resonating devices, both the quality factor and the resonant wavelength of each device can be affected by the fabrication process. Recovering from these variations can be a challenging problem. Here we show the ability to restore a complex filtering system composed of multiple ring resonators. We use devices that enable independent thermal tuning of the quality factor and wavelength. We use an evolutionary algorithm to identify the degree of tuning needed for each parameter of the system to restore the original performance.

The filter system shown here is based on four pairs of coupled ring resonators. The particular arrangement shown in Figure 1(a) enables tuning of the quality factor in addition to the resonant wavelength. In this coupled system the quality factor of the mode circulating in both rings is highly dependent of the relative resonant wavelengths of the two rings [5]. The microring pairs are made up of equally sized rings set apart by πR, where R is the ring radius, effectively making a racetrack which is twice the path length of a single ring. The pairs are then spaced symmetrically between two waveguides: one which carries the signal and the other which extracts the filtered light. The ends of the extracting waveguide are tapered to reduce reflections.

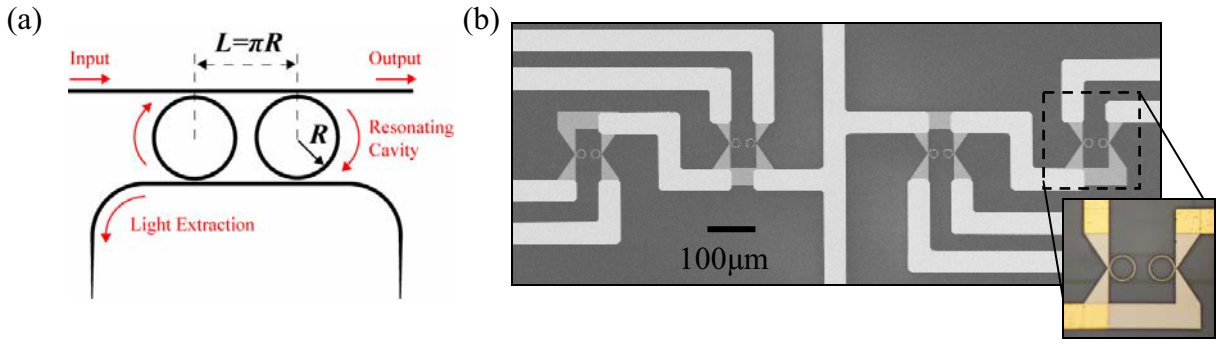


Figure 1: (a) Schematic for an individual ring pair. (b) SEM of the full thermo-optic system with microscope image insert.

We tune the resonant wavelength of each ring thermally using electrically controlled metal heaters located above each ring as pictured in Figure 1(b). This change in temperature within the silicon alters the refractive index n_{Si} of the material by the experimentally verified relation between index and temperature $\frac{dn_{Si}}{dT} = 1.86 \times 10^{-4} K^{-1}$ [6]. The change in n_{Si} modifies the effective path length around each ring, and with it the resonance condition $2\pi R n_{eff} = m\lambda$ where m is an integer, and n_{eff} is the effective index based on n_{Si}.

Fabrication is done on an SOI substrate with a 240 nm silicon layer on 3μm buried oxide. We use 450 nm wide rectangular Si waveguides made by e-beam lithography, reactive ion etching and clad with a 1 μm PECVD oxide

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layer. The oxide is planarized using chemical mechanical polishing to avoid pinching and other variations when depositing the metal. The heaters and contact pads are then fabricated from nickel and gold, respectively, above the cladding using an e-beam, evaporation and lift-off process. The thickness of the nickel is 100 nm with a 5 nm Ti adhesion layer. Because of the small size of the heaters and the devices, the power consumed by each heater is less than 1mW per nm shift in wavelength.

In order to get the best match between the fabricated filter and our objective filter, an evolutionary algorithm is employed to calculate the optimal tuning parameters [7]. The algorithm is first given measured parameters from the ring resonators such as the round-trip loss of the rings α, the field coupling coefficient κ and the phase shift Φ from the ideal resonances. The algorithm uses these parameters as the bounds to minimize the mean squared-error between the target spectrum and the possible tuned filter response according to:

$$MSE = \sum_i \left(T(\lambda_i)' - T(\lambda_i)\right)^2$$

where $T(\lambda_i)'$ is the transmission of the fabricated filter, and $T(\lambda_i)$ is the transmission of the target filter. Using stochastic operations such as mutation, recombination and selection processes the algorithm tests a multitude of solutions until it finds the best match. The result is given as a shift Φ for each ring in the device. Figure 2(a) shows the algorithm fitting a simulated damaged filter to a target transmission function.

To demonstrate the performance and flexibility of the fabricated system we show in Figure 2(b) the transmission function of three different filters. A ramp, a band-pass and a double band-pass function are all dynamically created using the same four ring-pair device. The demonstrated scheme, using an evolutionary algorithm to restore the integrity of the system is scalable to high-order filters with large numbers of parameters enabling complex functions on chip with the ability to recover from otherwise debilitating fabrication errors.

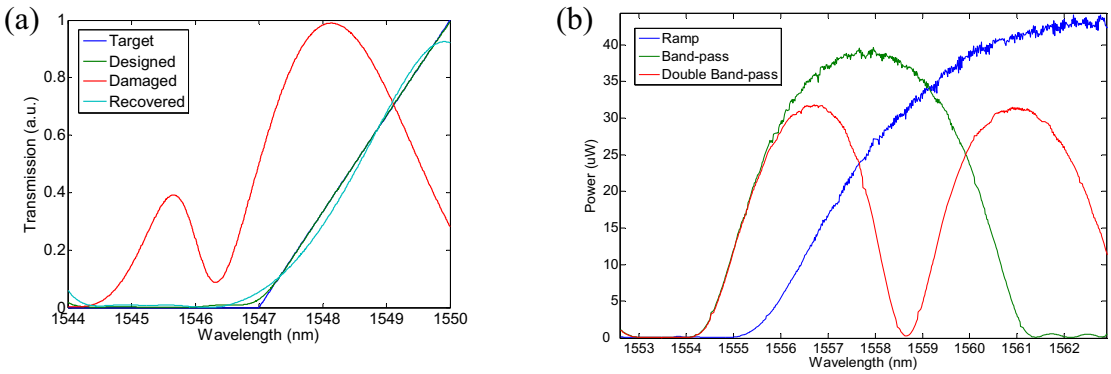


Fig. 2 (a) Simulated restoration of a ramp filter. (b) Experimental results of a filter dynamically tuned to fit three common filter types.

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