Parallel-Coupled Adiabatic Resonant Microring (ARM) Filter with Integrated Heaters

Michele Moresco[1], **Ehsan Shah Hosseini**[1], **Erman Timurdogan**[1], **Douglas D. Coolbaugh**[2], **Gerald Leake**[2], **Michael R. Watts**[1]

1: Research Laboratory of Electronics, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, USA
2: College of Nanoscale Science and Engineering, University at Albany, 257 Fuller Road, Albany, NY 12203, USA
mmoresco@mit.edu

Abstract: Add-drop filters based on parallel adiabatic resonant microrings (ARMs) are demonstrated. The ARM design permits synthesis of maximally flat characteristics up to a FWHM of 54 GHz while keeping the ripple amplitude below 1 dB.

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1. Introduction

Higher order resonant filters with large FSR allow maximization of the number of channels in a WDM link while minimizing the power consumption. Conventional second and higher order resonant filters [1] based on cascaded microring resonators require strict control of the resonant frequency of each ring. Nevertheless, unavoidable fluctuations due to photolithography variations make the fabrication of identical shapes quite challenging [2]. This results in an unpredictable filter response. Moreover, it is not possible to achieve partial drops with the same filter shape. Further, considering the tuning efficiency of adiabatic resonators, a serially cascaded filter suffers from higher order modes of the adiabatic resonators appearing in the transmission spectrum.

Here, we report the synthesis and characterization of second order filters based on adiabatic parallel-coupled microring resonators. The advantage of this approach relies on the fact that the two resonances can be tuned individually without affecting the mutual coupling. By splitting the degeneracy we are able to arbitrarily synthesize the filter response, spanning from a Lorentzian shape to a Butterworth response. The full width half maximum (FWHM) bandwidth can be tuned from 23 GHz to 54 GHz while keeping the amplitude of the ripples below 1 dB. The ARM design allows to directly heat the silicon, thus enabling the two rings to be independently controlled because of the difference in thermal conductivity between the silicon and the surrounding silica [3].

2. Filter Design

The design of the parallel-coupled or quarterwave-coupled resonator filter [4] is presented in Fig.1. The two microring resonators are mutually coupled by two identical sections of waveguides, whose lengths L_C must be an odd multiple of a quarter wavelength in order to sustain the desired mode. The rings are placed as close as possible to each other to minimize fluctuations in the phase caused by the photolithographic process, but far enough so as to not directly interact.

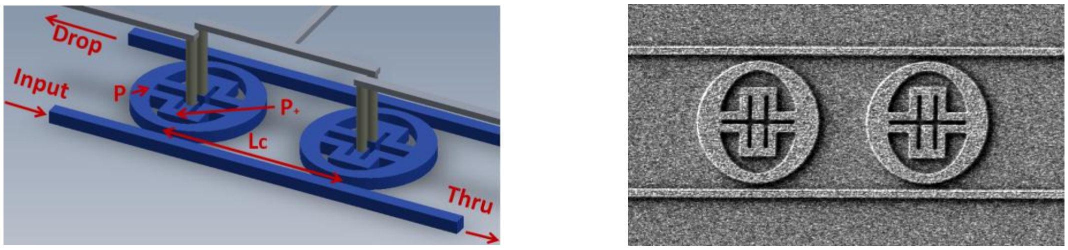

Figure 1 – (Left) Illustration of the parallel-coupled filter design. Highly doped tethers are placed in the middle of the rings. The low-doped heaters are integrated in the wide section of the ring. The radius of the microring is 3µm and the separation of the resonators Lc is 8.763 µm. The p and p^+ doped areas are shown. (Right) A top view SEM of the filter.

We use a similar adiabatic filter approach to that described in Ref. [3]. As the ring waveguide widens from 480 nm (close to the bus waveguide) to 1100 nm (90^o away from the bus waveguide) light propagates in a single transverse mode while not suffering from losses due to the tethers connected to the wide region. Adiabatic ring resonators (ARMs) enable both high Q and large FSR with direct interior electrical contacts to the microring. Each ARM resonator is integrated with heaters formed by low-doped regions within the microring. The resonance of each microring is thermally tuned by applying a voltage bias across the heater [5]. The radius of the microring is 3 µm and the separation between the resonators L_c is 8.763 µm.

3. Results

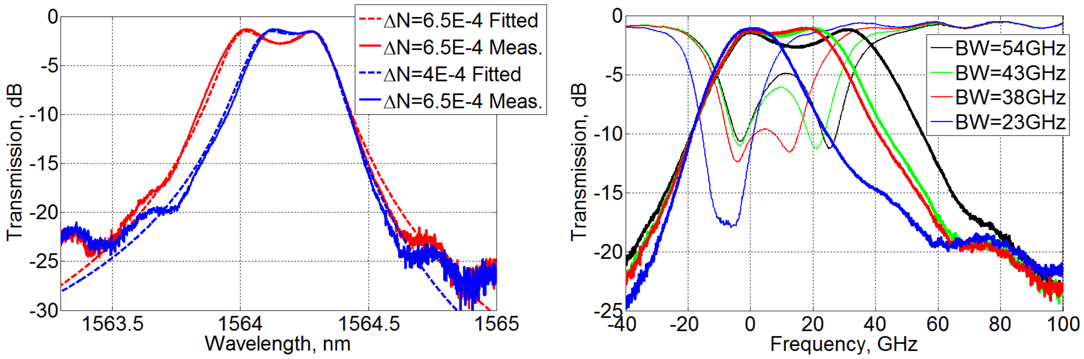

Figure 2 - (Left) Two filter responses have been measured and fitted with a transfer matrix approach. The red solid and dashed curves represent the measurement and fitting respectively for an index detuning of 6.5×10^{-4}, while the blue solid and dashed curves represent the measurement and fitting respectively for an index detuning of 4×10^{-4}. (Right) A set of measured filter responses showing optical bandwidths of 23 GHz (blue curve) to 38 GHz (red curve), 43 GHz (red curve) and 54 GHz (black curve).

The filter spectral response was characterized with a tunable CW laser source. Light is coupled into the TE mode of the waveguide by lensed fibers and the integrated heaters are driven with a 100-µm-pitch SGS probe, which allows individual control of each ARM heater. By varying the refractive index of the heated section of each microring, one can arbitrarily red-shift the two filter responses. Notice that a direct heating of the silicon would not be possible with over clad heaters. Figure 2 (left) shows two filter responses which have been obtained respectively by thermally detuning the refractive indexes by 6.5×10^{-4} and 4×10^{-4}. The responses have been fitted with a model based on the transfer matrix approach, showing very good agreement with experiments. Figure 2 (right) shows how the filter response can be modified by detuning the microrings. The frequency response is that of a Lorentzian-like filter as the detuning approaches zero. As the detuning is thermally increased the peaks of the resonances begin to split resulting in a larger bandwidth. The response remains sufficiently flat up until a FWHM of approximately 54 GHz (the amplitude of the ripples at 54 GHz is 1dB). However by engineering the amount of energy coupled from the bus into the rings, the bandwidth can further be improved. In the current experiment, all gaps were nominally 250 nm, resulting in a bus-ring coupling constant of approximately -17 dB. The filter can be red-shifted by up to 23 nm, corresponding to a driving voltage of 12 V. However, the frequency responses shown in figure 2(left) and 2(right) are not conserved across the entire 23 nm-span. In fact, because the phase shift over one microring round trip is comparable to that accumulated across a distance equal to $2L_C$, a red-shift of only a fraction of the FSR is required to break the phase difference necessary to maintain the desired filter response. In order to make the filter tunable while keeping the response unchanged, in future designs L_C will be decreased to a fraction of the microring perimeter. This way, the phase shift accumulated along the upper and lower waveguides would not have any major impact.

4. Conclusions

A parallel-coupled tunable microring resonator filter has been presented. The optical bandwidth of the filter can be easily controlled by thermally tuning/detuning the two resonances through the ARM design. The response remains sufficiently flat up to approximately 54 GHz.

5. References

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