FSR free coupled microring resonator filter on extended C-band in silicon photonics

(Student Paper)

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ABSTRACT

In this work we present a modified Vernier scheme which allows the realization of FSR free filters based on coupled micro ring resonators overcoming the limits induced by the constraints on the physical dimensions of the cavities. We present a two stage optimization procedure to design a tunable filter with no FSR. Through experimental trials we demonstrate the design procedure on a 4 ring filter operating FSR-free over 60 nm.

Keywords: Photonic Integrated Circuits, Silicon Photonics, Ring Resonators, Optical Add Drop, Hitless Filters.

1. INTRODUCTION

High-order microring resonator (MRR) filters, typically with more than two series-coupled resonators, can leverage both the compact footprint sizes and the resonant characteristics of MRR to offer attractive spectral features such as wide passbands, steep roll-offs, and large extinction ratios that are desirable for a wide range of applications in telecommunication and computing systems. Silicon on insulator (SOI) MRR are good candidates for such filters because they can achieve the high bandwidth requirements while having compact footprints. Furthermore, by coupling resonators with different lengths and utilizing the Vernier scheme [1] we can extend the free-spectral-ranges (FSRs), leading to devices that can also operate over wide wavelength ranges. Extending individual FSR of resonators in Vernier scheme to achieve larger overall FSR of filter leads to excess bending loss in MRR which reduce the performance of the device. Not to mention smaller footprint of MRR limits the efficiency of thermo-optic actuators thus limiting the tunability of the device along the band. Considering a fair constraint on bending radius of MRR in SOI (about 7μm) the FSR of filter can barely reach 4.6THz for example 32nm in [2] and 36.7nm in [3].

In this work we propose a modified Vernier scheme, using non-integer ratio between MRR size, resulting to larger wavelength distances for alignment of all resonators which means wider FSR. Neglecting the dependent of couplers on wavelength, we can achieve 120THz of FSR with the same constraint on MRR bending radius (see simulation results in Fig.1(a) for a 4th order coupled MRR filter using this approach). In the next section we describe the optimization technique used to design a filter tuneable on 1520-1570 nm (well above the telecom extended C-band) using this modified Vernier scheme.

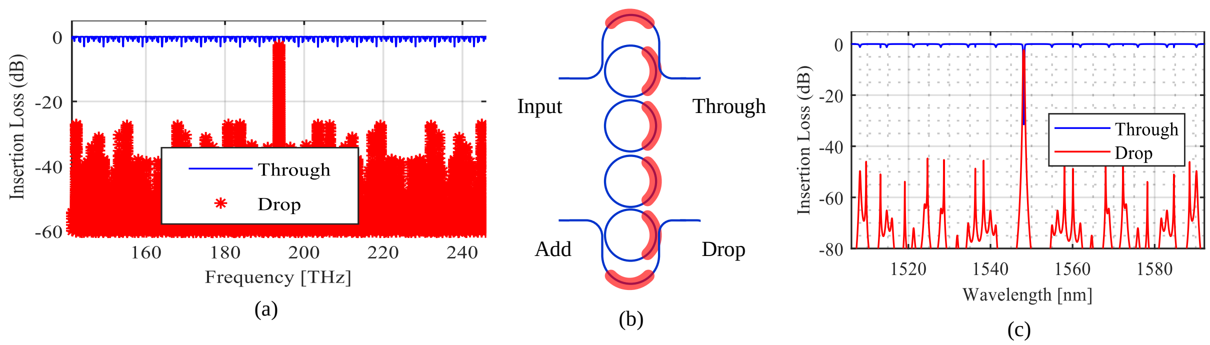


Figure 1: (a) Through and Drop port simulation of filter designed based on non-integer Vernier scheme neglecting the dependence of coupler on wavelength presenting more than 120THz of FSR. (b) schematic of 4th order Vernier filter with two tunable couplers connecting it to input/output bus waveguide. (c) Frequency response of 4th order filter with 40GHz bandwidth and more than 70nm of FSR.

2. Design of filter and simulation

A 4th order coupled MRR filter was designed with 40GHz of 3dB bandwidth along a 10 THz band (80nm). The Through port of the filter shows spurious out of band notches less than 1.2dB deep corresponding to out of band peaks on Drop port frequency response lower than 40dB. Two tuneable couplers are connecting this filter to the bus input/output waveguide allowing wavelength compensation for dependence of couplers along the band. The filter has a Butterworth spectral response. Schematic of this filter is presented in Fig.1(b). Design procedure consists of two stages, **I**: finding the best configuration of the non-integer Vernier scheme to have acceptable depth of notches (less than 1.5dB) and high of peaks (less than 20dB) in Through and Drop port frequency response along the wide operating wavelength range; **II**: optimizing the couplers between MRRs to satisfy requirements on filter performance along the wide spectral range. This requirement includes 40GHz of 3dB bandwidth, 18 dB of in-band isolation and 20dB of off band isolation in 50GHz distance from the centre of the filter. An optical simulator is developed capable of simulating different configuration of Vernier filter with appropriate coupler values. This simulator considers the dispersion of the waveguide and dependence of couplers on wavelength along the band. It can shift the simulated filter along the band while evaluating its performance which is used as merits in optimization procedure.

Design procedure starts from the best integer configuration (conventional Vernier scheme) of the Vernier filter (with 4.6THz of FSR) and introduce random coarse perturbations in the configurations to find a one with larger FSR equal to 10THz. In the winner candidates, finer perturbations are introduced to find the cases that satisfy two criteria's **A**: depth of notches out of band in Through port lower than 1.5dB; **B**: height of peaks out of band in Drop port lower than 20dB. Performance of device, in terms of bandwidth and isolation, is evaluated on chosen filters from previous steps. These filters are shifted along the band to the min wavelength at 1520nm and end of band at 1570nm (considering the variation of couplers and effective refractive index) and their performance is evaluated. Second part of design continues by optimizing values of couplers between MRR to satisfy the requirements along the band on chosen cases from previous optimization step. At the end of this procedure winner cases are filters capable of satisfying requirements along the extended C-band. To encounter fabrication tolerances, expected variations are simulated in these filters to understand the standard deviation of performance along the band and the best candidate is chosen. This tolerance analysis is done for coupler values and waveguide width (in form of variation of MRR radius and effective refractive index). Frequency response of this filter (with MRR ratio of [5.73 3.3 4 4.8]) for Through and Drop port is presented in Fig.1(c) and performance of filter along the extended C-band is presented in table below.

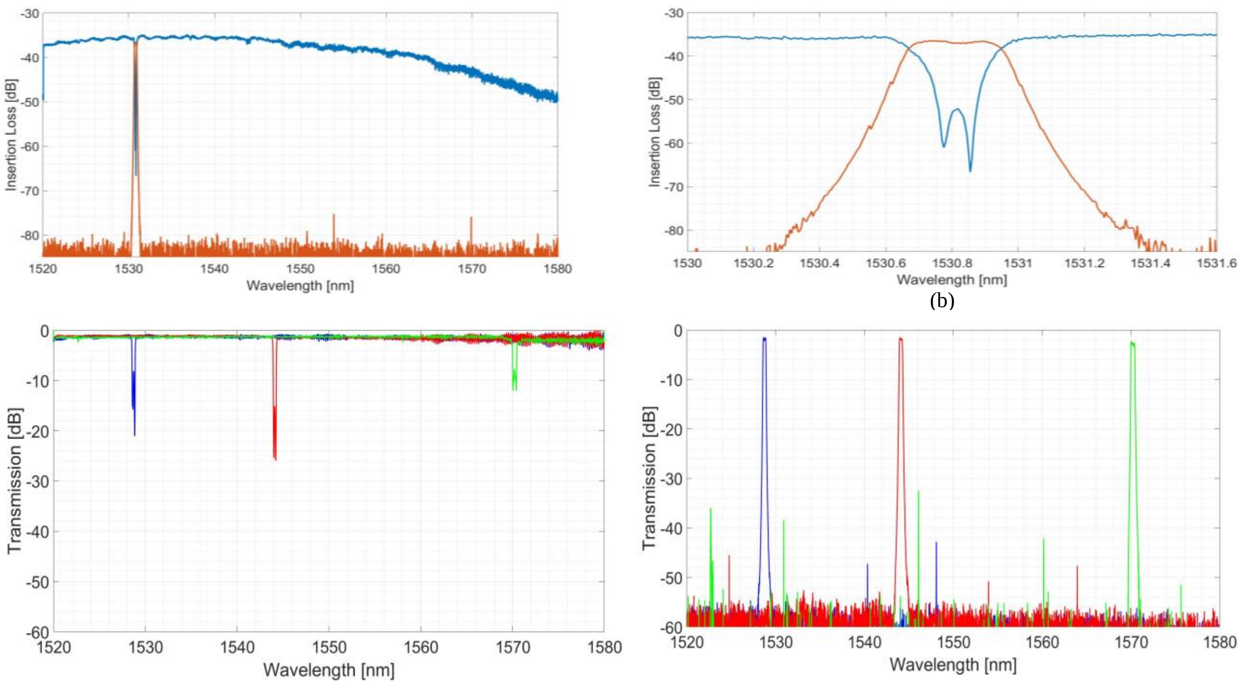
Vernier Filter	**3dB Bandwidth**	**50GHz Channel Isolation**	**100GHz Channel Isolation**	**Max Port Isolation**	**MAX Out of Band Notch Depth**
@ 1545 nm	43.9 [GHz]	-22.5 [dB]	-51 [dB]	-28 [dB]	-1.2 [dB]
@ 1570 nm	47.9 [GHz]	-20.1 [dB]	-50 [dB]	-20.5 [dB]	-1.2 [dB]
@ 1520 nm	39.5 [GHz]	-25.2 [dB]	-53.2 [dB]	-25 [dB]	-1.2 [dB]
Specification	40 [GHz]	20 [dB]	30 [dB]	18 [dB]	-1.1 [dB]

3. Experimental Results

In this section we show experimental results of this 4th MRRs filter fabricated in silicon photonic platform. More specifically we demonstrate automatic tunability across the wavelength range 1520-1570nm (larger than the extended C band). Automatic tuning of this filter is done using gradient descent technique while cancelling the effect of thermal cross talk by thermal eigenmode decomposition (TED) in [4]. A tuneable signal with 40GHz bandwidth (to match with filter design) is used to find the optimum response of filter along the band.

Figure 2(a) shows the measured transmission at Drop (orange) and Through (blue) ports of the filter, when the passband is tuned at a wavelength of 1530.8 nm. Since the design of filter is based on non-integer Vernier scheme, the filter is FSR free well above the extended C band and indeed no other passbands are visible in the measured wavelength range. At the Through port, only a couple of off-band notches are visible which are within the specification limits. Most significant one has a depth of less than 1.5 dB at 1545 nm. At the drop port, off band peaks are more than 45 dB below the in-band transmission.

Figure 2(b) shows zoomed of filter response at the tuned wavelength. We can observe that the in-band loss and the in-band ripple at the drop port is less than 0.5 dB. The 3dB bandwidth is about 43 GHz, which is in line with what has been defined during the design phase. Channel isolation at 50 GHz is about 22 dB, and more than 45 dB at 100 GHz for non-adjacent channels.



(c) (d)

Figure 2: (a) Spectral response of the 4th order MRR filter (blue, through port, orange, drop port). (b) Zoom around the wavelength of interest. (c) Measured transmission at Through port of the filter tuned at three different channels over the entire extended C band. (d) Measured transmission at Drop port of the filter tuned at three different channels over the entire extended C band.

In band isolation at the Through port is about 16 dB (worst case in a passband of 20GHz), but we expect that this parameter can be improved by finely tuning the input/output MZI coupler to optimize the impedance matching of the filter to the bus waveguides.

The filter has been tuned at three different channels close to the lower limit (1528.5 nm), the center (1544.4 nm) and the upper limit (1570 nm) of the extended C-band. Results shown in Figure 2(c) for Through port and 2(d) for Drop port proves the feasibility of covering a very wide wavelength range with a thermally tunable MRR filter.
We want to underline that the filter has been tuned at these three new channels using the automated algorithm mentioned before. Spectral parameters are significantly varying along the frequency domain due to non-negligible impact of the coupler variation with wavelength. Nonetheless, the filter appears FSR free in each tuning condition.

4. Conclusion

In this work we present a modified Vernier scheme design for coupled microring resonator filters presenting extremely large FSR. We demonstrated a 4th order filter with more than 60nm FSR, well above the extended C-band. Through presented optimization techniques this filter demonstrates 40GHz of bandwidth alongside 20dB of isolation off band at 50GHz over the considered spectral range.

5. Bibliography

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