Tunable Bandwidth Microring Resonator Filters

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Abstract

Tunable bandwidth, tunable line-shape filters are realized by incorporating Mach-Zehnder interferometers as directional coupler elements within higher order microring resonators. A flat-top bandwidth tuning range of 2.7 GHz to 21 GHz is demonstrated.

Introduction

Compound microring resonator filters have proven indispensable for high fidelity filtering and signal processing in DWDM and RF photonic applications [1]. These filters have frequencies that are readily tuned by changing the refractive index of the rings, for instance by the thermo-optic or electro-optic effect. The bandwidth and line shapes are fixed by the coupling strengths between the rings and input/output waveguides, and the coupling between adjacent rings. The coupling is determined by the physical gap or separation between adjacent waveguides as in Figure 1. Tunable bandwidth filters add a new degree of freedom, and are desirable in adaptive applications such as matched filtering, ASE filters, or in RF photonic receivers. Tuning the bandpass characteristics is not readily achieved through index changes in the ring's evanescent directional couplers. Tunable bandwidth filters having rings coupled in parallel to Mach-Zehnders have been demonstrated in silicon technology [2]. Here we demonstrate wide bandwidth tuning by incorporating Mach-Zehnders in place of directional couplers directly within higher order resonators. The losses are an order of magnitude lower than those reported in [2], while maintaining superior line shape, crosstalk performance, and bandwidth tuning range.

Filter Design and Fabrication

A schematic of a 3rd order tunable bandwidth filter is shown in Figure 2a. The tunable couplers (boxes with arrows through them) are implemented as Mach-Zehnder (MZ) interferometers, as depicted in Figure 2b. Thin film thermo-optic phase heaters placed on the arms of the MZs control the coupling from the input or output waveguides, or between adjacent rings. Phase heaters on portions of the ring tune the resonant frequencies. In the foregoing implementation, the MZ heater simultaneously tunes the resonant frequency through a phase change in the MZ, however this is offset by the ring phase heater.

Filters were fabricated using Hydex®, a commercial high index contrast dielectric material processed in a conventional silicon foundry [1]. The waveguides have cross sectional dimensions close to 1.5 μm x 1.5 μm. The refractive index of the waveguide cores are 1.70, while the clad has an index of 1.45. The rings were designed to have equivalent radii of 300 μm, giving Free Spectral Ranges (FSRs) of 100 GHz.

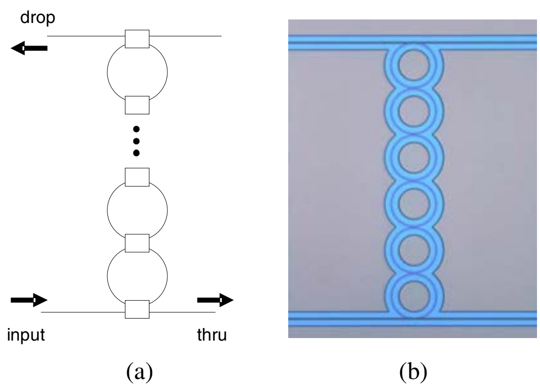

Figure 1: (a) Schematic of a high order microring resonator. (b) Example of a fabricated device having fixed ring-ring coupling.

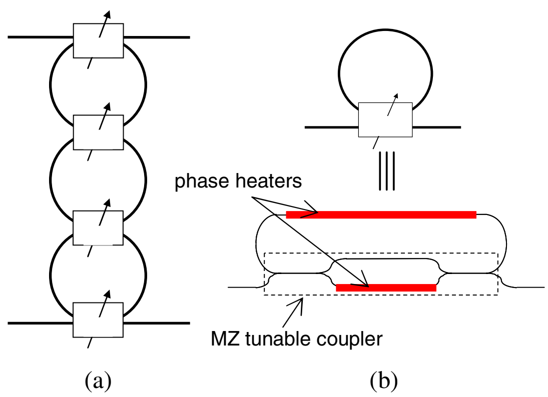

Figure 2: (a) Schematic of a tunable bandwidth microring resonator filter. (b) Implementation of the Mach-Zehnder based tunable couplers. Thin film heaters are used as phase shifters to tune the coupling ratio and resonator frequencies.

Measured Filter Characteristics

The MZ tunable couplers can adjust the coupling ratio over the full range of 0% to 100%, thus in principle a large range of bandwidths may be achieved. In high order filters, the ring-to-ring, input/output bus-to-ring, and frequency phase heaters, all need to be optimally adjusted to produce a desired flat-top shape for a given target bandwidth. In the 3rd order filter, seven variables need to be controlled. Figure 3 highlights three representative examples of filters having 3-dB bandwidths tuned to 2.7 GHz, 13 GHz, and 21 GHz. Figure 3b shows that in-band ripple can be reduced to below 0.2 dB. On-chip losses through the microring filter were less than 0.5 dB in each case.

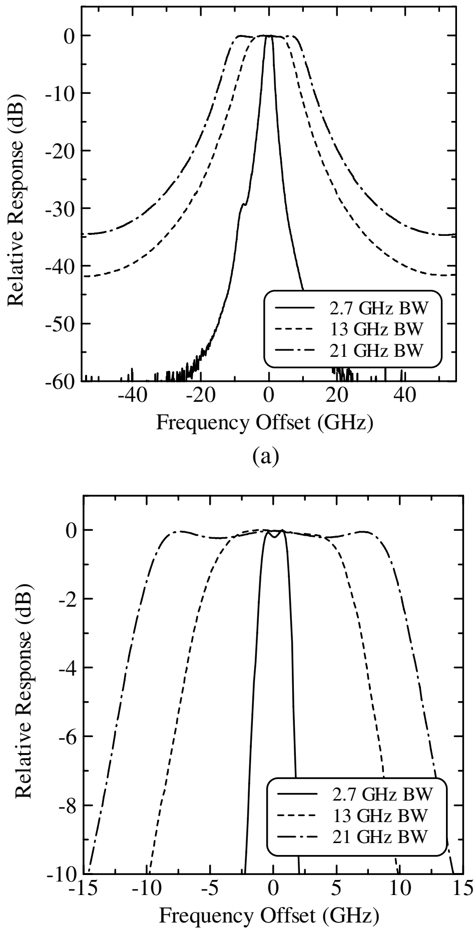

Figure 3: Representative measured filter responses in the tunable bandwidth filter. Three 3-dB bandwidths are demonstrated, 2.7 GHz, 13 GHz, and 21 GHz. (a) Shows the full filter characteristic responses, while (b) highlights low in-band ripple of < 0.2 dB.

In RF photonics and other applications that call for matched filtering, flat-top responses may not be the ideal. In high order filters, some line shape tuning is afforded by tuning the ring-ring coupling strengths relative to the ring-bus coupling. Generally the responses here are limited to Chebychev responses that trade off higher out-of-band roll-off for increased in-band ripple [3]. Figure 4 for example, demonstrates such a filter where the ring-ring coupling is tuned relative to the ring-bus coupling. Clearly in-band ripple is sacrificed for improved filter roll-off.

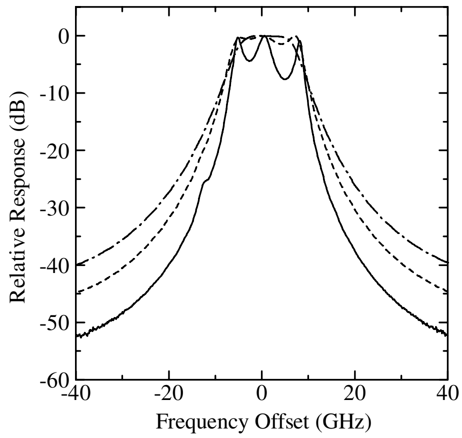

Figure 4: Examples for different Chebychev filter responses. The 3 dB bandwidth of the filter is kept constant while the relative ring-to-ring and ring-to-bus coupling strengths are varied. Steeper roll-off of the response is achieved at the expense of increased in-band ripple.

Conclusions

A high-index contrast PLC platform was used to fabricate low loss filters having tunable bandwidths. These filters expand the utility of frequency-tunable microring resonators. Early demonstrations show a bandwidth tuning capability of 2.7GHz to 21 GHz. Such filters can be arranged in a Vernier architecture for full C-band frequency tuning, as will be subsequently demonstrated.

References

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3. B. E. Little, et. al., “Microring resonator channel dropping filters,” *IEEE J. Lightwave Tech.*, vol. 15, pp. 998-1005, 1997.