Polarization insensitive tunable hitless filter for extended C band

(Student Paper)

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ABSTRACT

Controllable loss induced through variable optical attenuators integrated in microring resonators is exploited to implement a novel hitless tuning scheme for silicon photonic WDM filters. The proposed concept is demonstrated in a polarization insensitive architecture operating across the extended C-band.

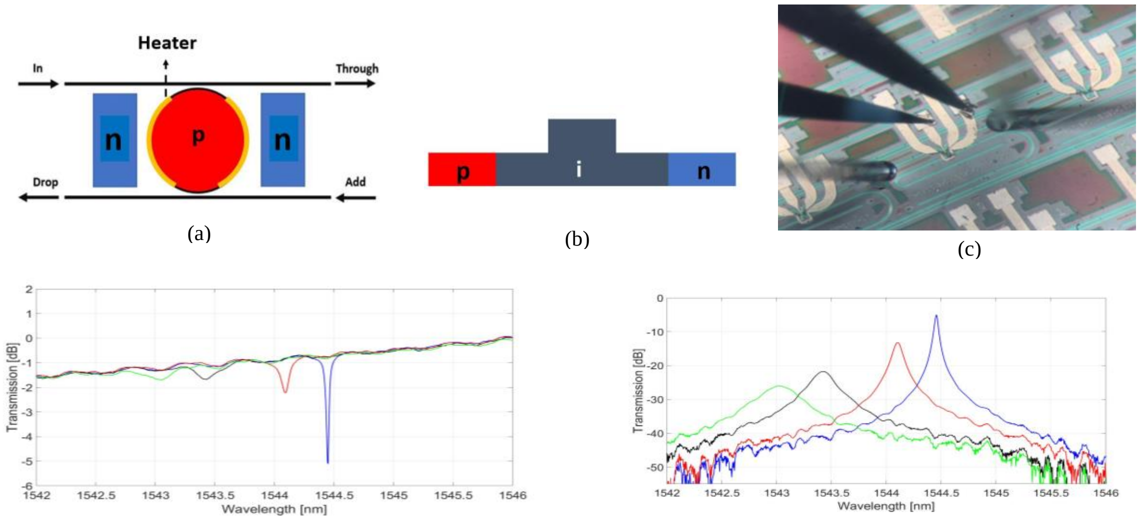
Keywords: Photonic Integrated Circuits, Silicon Photonics, Ring Resonators, Optical Add Drop, Hitless Filters.

1. INTRODUCTION

Tuneable optical filters are key functional building blocks of optical networks, where flexible allocation of WDM channels and dynamic channel routing between network nodes is required. Although silicon photonics is a promising platform for the realization of WDM filters, many issues have limited its use in real applications. Among all, the need for wide band filter tuneability (at least across the C telecom band), the possibility of implementing hitless tuning (that is without affecting other channels propagating in the same link) and the inherent polarization sensitivity of silicon waveguides have represented major limiting factors to their real implementation. Although several solutions have been proposed for the realization of silicon photonics hitlessly tuneable WDM filters [1], no one so far was demonstrated to solve all the above mentioned issues.

In this work we present a novel hitless tuning scheme for silicon photonic coupled-resonator WDM filters operating across the extended C-band. The proposed strategy exploits controllable loss induced through variable optical p-i-n attenuators integrated in the microring resonators, rather than tuneable couplers and/or selective detuning. These two techniques rely on phase shift applied to single parts of the system, which can lead to unwanted critical coupling issues, disrupting non resonant channels.

The proposed tuning concept is demonstrated in a 4th order filter, designed according to a new Vernier-based technique in order to provide wide FSR operation (> 100 nm) [2], which is integrated in a polarization diversity scheme guaranteeing polarization insensitive channel filtering.



(a) (b) (c)

(d) (e)

Figure 1: (a) Scheme of a single microring resonator with integrated p-i-n junction, acting as VOA. (b) Cross section of the waveguide the ring resonator is made by. (c) Microscope photograph of the ring with VOA and heater under test. (d) Through port disconnection steps, the voltages applied to the p-n junction are 0 V (blue function), 1 V (red), 1.5 V (black), 2 V (green). (e) Drop port disconnection steps, same voltages as figure (c)

2. Disconnection Mechanism for Hitless Tuning

In this section we present a novel disconnection mechanism, in order to effectively perform hitless tuning. While tuning from a channel to another the filter has to be disconnected from the bus waveguide, to avoid any disturbance in the channels between the starting position and the target one.

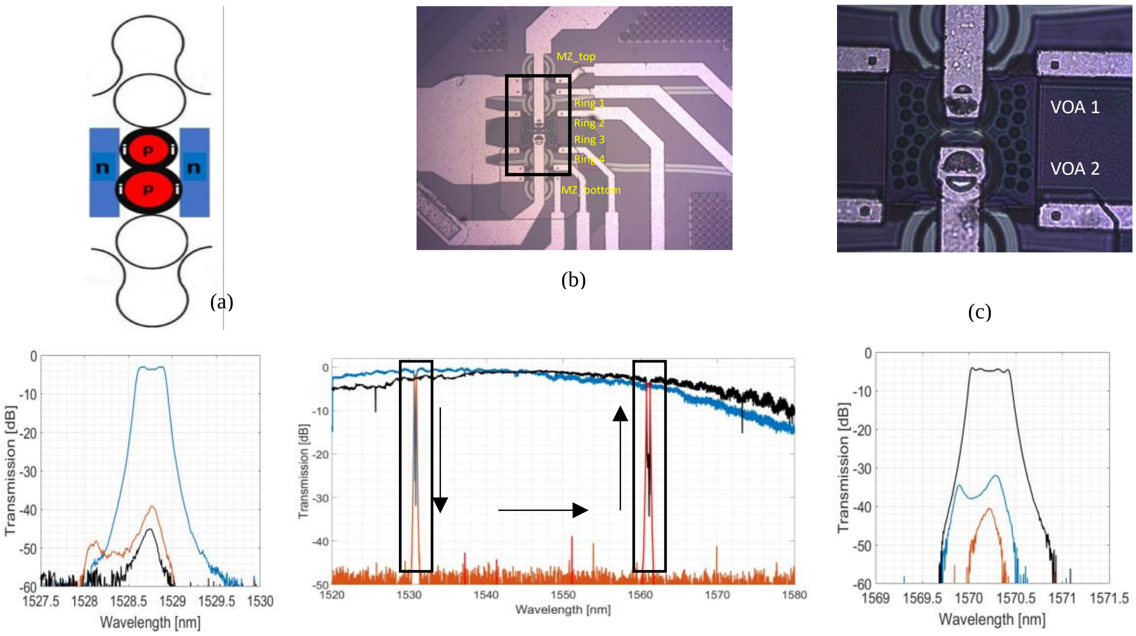
Since selective detuning and tuneable couplers can lead to unwanted critical coupling, we are going to present an approach that relies on the dismantlement of the resonance peaks, decreasing directly the power flowing inside the rings. This is possible implementing a Variable Optical Attenuator (VOA) inside the microring resonators. If the losses inside the MRR structure are large enough, the entire incoming optical power is conveyed to the through port, leaving the filtering architecture disconnected.

From a design point of view, the VOAs are implemented through p-i-n junctions integrated in the waveguide, as it is shown in Figure 1 (a) and (b). To do so, p-doped and n-doped regions have been put alongside the rib-waveguide, which is intrinsic.

When a driving voltage above the threshold (typically about 0.7 V) is applied between the ‘p’ and ‘n’ electrodes of the VOA, free carriers are injected into the waveguide, leading to a desired increase of the MRR round trip loss, which is also associated with an unwanted variation of the waveguide refractive index (according to the Soref formulas [3]). This shift is partially induced by waveguide heating (leading to an increase of the refractive index and thus to a red shift of the MRR resonances) and by free-carrier injection (leading to a decrease of the refractive index and thus to a blue shift of the MRR resonances). The latter effect is typically dominant, so that a residual blue shift of the MRRs is observed during “uncompensated” disconnection of the filter. Figure 1 (d) and (e) show the effect of disconnection on the frequency response of the single ring filter itself (Through and Drop port).

The concept is now extended from the single ring to a fourth order MRR filter, with 40 GHz bandwidth. FSR larger than 100 nm is achieved exploiting innovative Vernier scheme, with non-integer coefficients [2,4]. This device has been realized in Silicon-on-Insulator platform with rib waveguides 500 nm by 220 nm in size by AMF. The hitless mechanism is achieved by integrating p-i-n junctions inside the two innermost rings (second and third one) to realize VOAs as indicated in figure 2 (a), (b) and (c). The complete hitless tuning from the channel with central wavelength of 1530nm to 1560nm with a truly disconnect state is shown in fig. 2 e). This demonstrates the hitless tunability across an extended C-band. The detrimental impact on neighbour channels of the p-n junction induced blue shift is thermally compensated during the disconnection and connection phases using the heaters integrated in the MRRs. Figure 2 (d) and (f) show the (dis)connection process of the filter with VOA and heaters automatically controlled by monitoring the drop port signals. Filter disconnection (> 35 dB isolation of the drop port transmission) is achieved with 0.95 V for VOA1 and 1.3 V for VOA2.

Thanks to the thermal compensation, the MRRs resonances remains within the bandwidth of the filter and the off-band rejection (for a 50 GHz spaced channel) is larger than 30 dB. Remarkably, negligible off band notches and



(a) (b) (c)

(d) (e) (f)

Figure 2: (a) Scheme of the 4th order MRR filter with integrated p-n junction, acting as VOA. (b) Microscope photograph of a 4th order TOADM filter with tunable MZI couplers in the first and fourth MRRs and integrating VOAs in the inner MRRs. Heaters, via holes and metal lines are clearly visible in the picture. (c) Detail of the rings with VOAs. (d) Detail of disconnection steps of 1530 nm channel (sequence: red, blue, black). (e) Tuning of two channels at the edges of the extended C-band (1530 nm and 1560 nm). (f) Detail of reconnection steps of 1560 nm channel (sequence: red, blue, yellow).

ripples appear in the through port filter response all over the extended C-band wavelength range even during operation, demonstrating the effectiveness of the proposed architecture. In the considered example, the most relevant notch is only 0.8 dB deep and 60 GHz as bandwidth, inducing an almost negligible impact on the performance of the whole system.

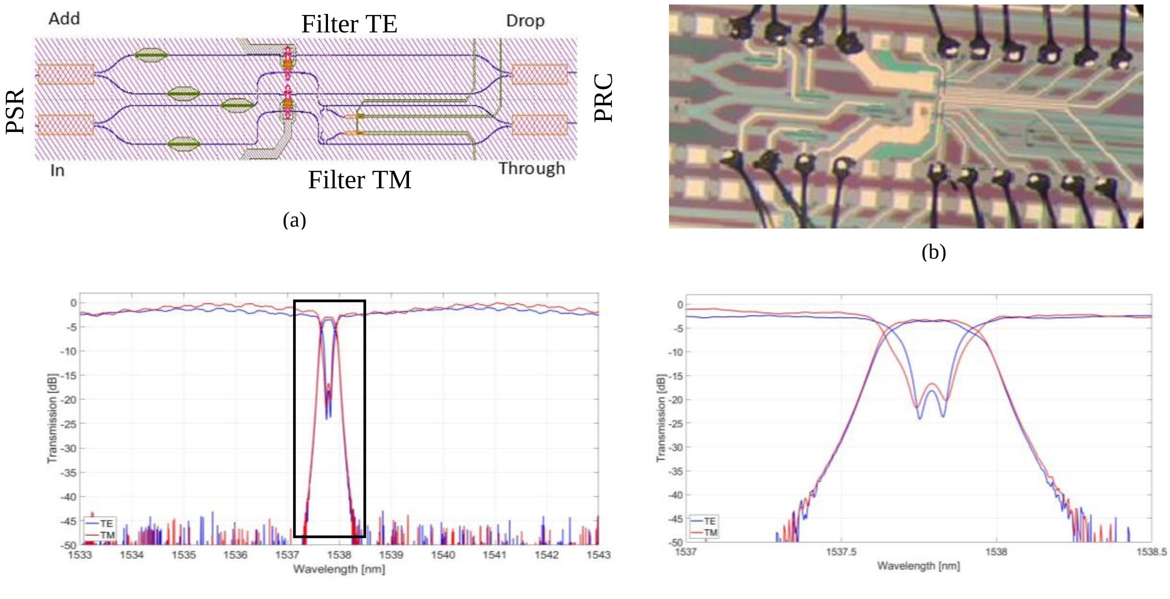
3. Polarization Diversity Scheme

Figure 3 shows the mask layout (a) and the top-view photograph (b) of the Polarization Diversity Filter. The Input and Add ports of the filter own a Polarization Splitter and Rotator (PSR, foundry proprietary design) that splits the incoming signal polarizations in two separate waveguides and rotates the TM polarization to have all the waveguides of the circuit operating in TE mode only.

To ease calibration operations, VOAs (implemented though a linear p-i-n junction) are integrated in both arms of the polarization diversity scheme. The two 4th order MRR filter are nominally identical and are individually controlled. At the output, a polarization rotator and combiner (PRC) is used to rotate from TE to TM the mode that was not rotated before, and then combine the two orthogonal modes at the output.

At first, the two filters of the polarization diversity scheme have been separately characterized. To this aim we controlled the polarization state of the input signal in order to calibrate the upper filter for operation on TM polarized input light and the lower filter on TE polarized input light.

Figure 3 (c) and (d) show the TE (blue) and TM (red) frequency response of the polarization diversity TOADM filter when both filters are tuned at a wavelength of 1537.8 nm, on a wavelength span of 4 nm around the considered channel.



(a)

(b)

(c)

(d)

Figure 2: Mask layout (a) and photo (b) of the Polarization Diversity MRR Filter. (c) Tuned filter responses of Through and Drop ports with separated TE and TM polarized input signals. (d) Detail of the inband spectral responses.

The spectral behavior of the two filters are almost the same in terms of bandwidth (40GHz) and in band rejection (nearly 16 dB). Moreover, the FSR is higher than 50 nm and there are no side notches across the entire extended C-band. From the tuning point of view, the voltages applied to the heaters of the two different filters are very similar, which leads to a certain reproducibility of this kind of devices.

BER and other system testing with generic input polarization states are in progress.

4. CONCLUSION

Reported results demonstrate for the first time the feasibility of an architecture to achieve a polarization independent, hitless, tuneable filter operating over an extended C band of 50 nm in silicon photonics.

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