Polarization Transparent Add-Drop Multiplexer with Hitless Tuneability

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Abstract *An original microring-based filter exploiting non-rational Vernier scheme and controllable ring losses with FSR-free frequency response and wide range hitless tuneability is reported. Effectiveness of the device as Add/Drop multiplexer is demonstrated through BER assessments on 200 Gbit/s 16-QAM DP signals.*

Introduction

Tuneable filters enabling dynamic WDM channel allocation are essential components of flexible optical networks. During the switch from a channel to another one, perturbations to other wavelengths must be avoided, this feature being known as hitless tuning. Silicon photonic filters, based on microring resonators (MRRs), are good candidates for this kind of applications, but their operational wavelength range suffer form free-spectral range (FSR) limitations, due to the minimum bending radius (>7 μm). Vernier schemes employing MRRs with different radii have been successfully used[1],[2] achieving FSRs in the order of 40 nm. Several approaches have been also proposed to hitlessly tune a MRR filter, such as the use of selective detuning of the resonances[3]. However, this technique is hardly applicable for a Vernier-based filter, due to the appearance of spurious notches and peaks in the spectral response during the operations.

In this work the concept and the design of a 4th order MRR filter, made on a Silicon-on-Insulator (SOI) platform is presented. Besides polarization insensitivity, two novel aspects are discussed. First, the use of a Vernier scheme, with non-integer ratios among the MRR radii, leading to a wide band of operation (> 90 nm, C+L band). Second, the introduction of controllable round-trip losses, in the resonators, to effectively disconnect the filter from the bus and so obtaining hitless tuneability. Effectiveness of these proposals has been proved through transmission experiments using 200 Gbit/s 16-QAM dual polarization (DP) signals .

Design of the 4th Order filter

As shon in Fig. 1(a), the proposed filter is composed by four coupled MRRs, having different radii according to non integer ratios. This design starts from a conventional (integer ratios) Vernier filter, which is then modified by using a

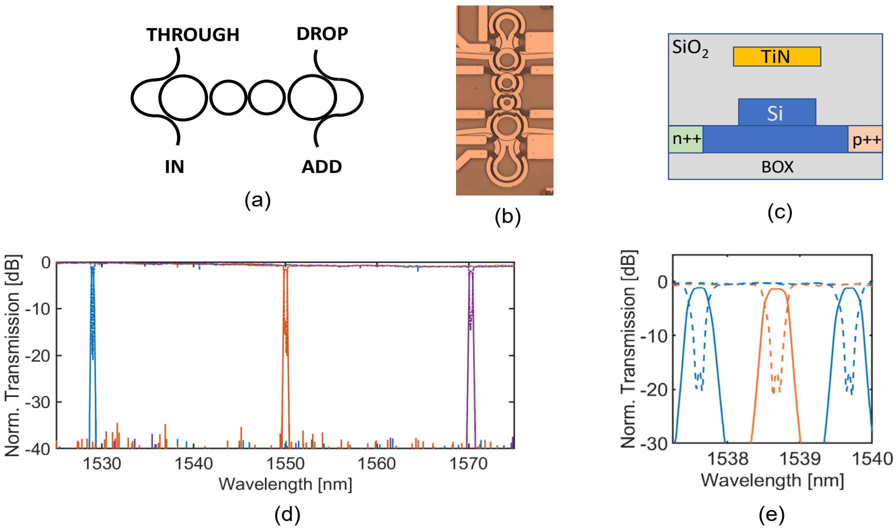

Fig. 1: 4th order MRR filter. (a) Schematics and (b) microscopic picture of the device. (c) Rib waveguide (500 nm by 220 nm) with TiN microheater and p++ and n++ doped regions. (d) Filter passband tuned at the beginning (around 1530 nm, blue), at the center (around 1550 nm), at the end (around 1570 nm) of the C-band. (e) Detail of three contiguous ITU-T channels around 1539 nm.

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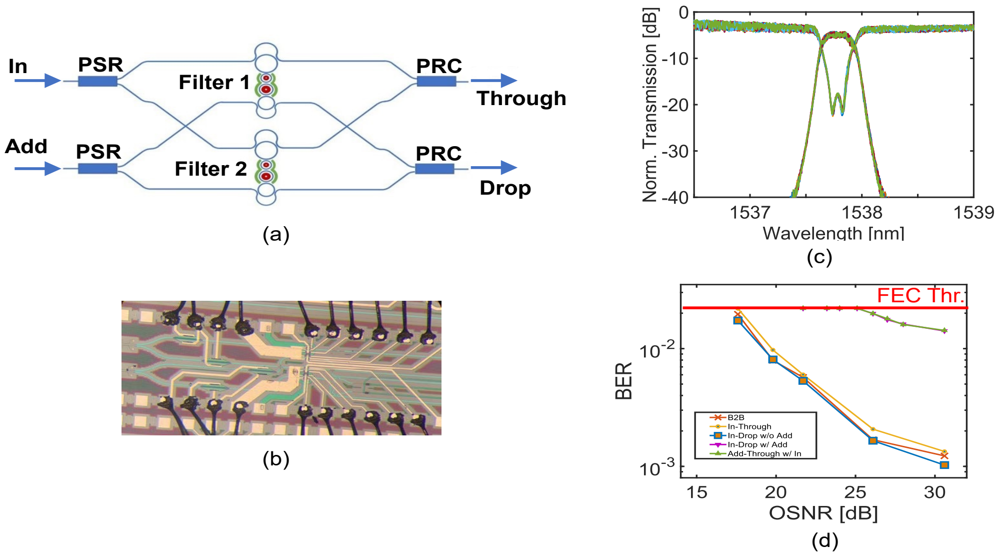

Fig. 2: (a) Polarization diversity scheme: PSR, two identical Vernier filters, PRC. Both filters are operating in TE mode. (b) Microphotograph of the wire-bonded device. (c) Through and Drop port spectral responses measured employing a polarization scrambler at the input port. Measurement repeated 10 different times. (d) Pre-FEC BER curves with respect to OSNR, in different operating conditions (specified in legend). Red line is FEC threshold.

suitable numerical optimizer based on non-integer FSRs, avoiding spurious passbands, while keeping the spectral shape of the passband in line with specifications. Eventually, the obtained radii ratios are [5.73 3.3 4 4.8], while coupler coefficients are [7%, 1%, 0.3%, 0.8%, 6%]. The MRRs are connected to the bus waveguides by tuneable couplers (tuneable Mach-Zehnder interferometers) to compensate for wavelenght dependence of the directional couplers. A microscopic picture of the fabricated SOI filter is shown in Fig. 1(b), while Fig. 1(c) shhows the cross section of the waveguide (220-nm, commercial silicon foundry[4]), with microheaters above. These thermo-optic actuators provide full recofigurability for each MRR, permitting to perform effective and automatic tuning of the filter, using thermal cross-talk free algorithms[5],[6]. The filter can be tuned to different channels of the WDM grid, as shown in fig. 1(d), while maintaining an aperiodic spetral response. A detail of the passband is reported in Fig. 1(e), for three different wavelengths around 1539 nm. The Drop port response has a 3dB-bandwidth of 40 GHz, 20 dB of out-of-band isolation (evaluated at 50 GHz from central frequency) while the Through port shows a return loss of 18 dB and shallow spurious notches, whose depth is less than 1.2 dB.

Polarization Transparency

Polarization transparency is implemented by using the scheme of Fig. 2(a) employing a pair of Polarization Splitter and Rotator and Polarization Rotator and Combiner (PRC)[4] according to a conventional polarization diversity scheme[7]. A photograph of the whole device is reported in Fig. 2(b). Fig. 2(c) shows the spectral response of the filter measured several times (ten curves overlapped) by changing randomly the input polarization during the wavelength scan (each point of each curve corresponds to a random state of polarization), resulting in a polarization dependent loss of less than 2 dB.

To verify the polarization transparency , we performed system level measurements, assessing (pre-FEC) Bit-Error-Rate (BER) on a 200 Gbit/s DP -16QAM signal for different values of OSNR. The reference curve labelled as In-Through (yellow one) in Fig. 1(d) is measured when the passband of the filter is tuned 10 nm away from the signal carrier wavelength. Compared to the back-to-back scenario (orange curve), i.e, connection between transmitter and receiver with a standard fiber, there is no performance degradation, demonstrating that the polarization diversity scheme (PSR-PRC) gives a negligible impact. Likewise, the In-Drop response (blue curve) shows no OSNR penalty. In the presence of an interfering signal coupled at the Add port (same wavelength as the signal launched at the In port), some residual crosstalk is observed, introducing an OSNR penalty of almost 10 dB, while remaining below the FEC threshold of the transceiver. Since the Add-Through BER curve and the In-Drop curve overlap, a symmetric behaviour of the Vernier filter can be asserted.

Hitless Tuneability

During the reconfiguration process the filter has to be disconnected from the bus waveguide, not to impairing the transmission of other wavelengths. We propose an approach based on

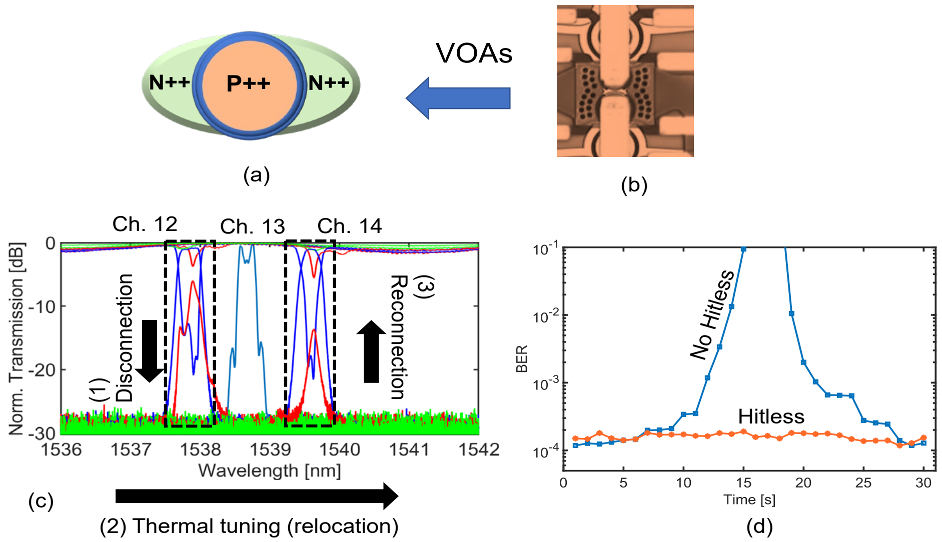

Fig. 3: Fig. 3: (a) Scheme of P-i-N junction implementing the integrated VOA in the central ring resonators. (b) Microphotograph of the filter with VOAs detail. (c) Hitless reconfiguration of the filter from Ch. 12 to Ch. 14 of the ITU grid with the spectrum of the reference signal (200 Gbit/s DP-QAM) at Ch. 13 (d) Time evolution of BER (of the reference signal) with and without hitless reconfiguration.

the exploitation of controllable losses induced in the MRRs of the filter. To do so, we integrated a p-i-n Variable Optical Attenuator (VOA) in the rib-waveguide, as depicted in Fig. 3(a). When the junction is forward biased (> 0.7V), free carriers are injected in the waveguide core, incresing the losses. Only the two inner MRRs are equipped with a VOA, as shown in the microscopic picture in Fig. 3(b), in order to avoid critical coupling of the first MRR, causing the appearence of deep notches in the In-Through spectrum. When free carriers flow into the waveguide, not only the losses are increased, but also the effective refractive index (n_{eff}) decreases, due to plasma dispersion effect[8]. This leads to a substantial blue-shift of the spectrum, dominating the thermal red-shift, caused by unavoidable temperature rise. This means that when the filter is disconnecting, the passband is attenuated and at the same time shifted towards higher frequencies. To counteract this unwanted side effect we use microheaters, real-time compensating for the net blue-shift. Figure 3(c) shows the complete hitless tuning path, lasting a few tens of milliseconds: 1) disconnection, 2) filter relocation, 3) reconnection. During the switch the passband remains within its own channel spectral window and niether spurious notches (at Through response) nor spurious peaks (at Drop response) appear.

Figure 3(d) shows the time evolution of the BER measured on the 200 Gbit/s DP -16QAM signal (whose spectrum is tuned at Ch. 13) while the relocation of the passband occurs, from Ch. 12 to Ch. 14. Using a non-hitless approach, the BER dramatically increases when the filter passband overlap the signal spectrum (blue curve), while employing the proposed hitless approach there is no appreciable BER change (orange curve).

Acknowledgement

The authors acknowledge the staff of Polifab, Politecnico di Milano, for the device assembly and Jabil Photonics for providing the transceiver. The work has been supported through H2020 grant number 871658 (Nebula).

References

[1] G. Griffel, “Vernier Effect in Asymmetrical Ring Resonator,” Photonics Technology Letters, vol. 12, no. 12, 2000.

[2] Y. Ren, D. Perron, F. Aurangozeb, Z. Jiang, M. Hossain and V. Van, “Silicon Photonic Vernier Cascaded Microring,” Photonics Technology Letters, vol. 31, no. 18, 2019.

[3] Douglas Aguiar et al. “Automatic Tuning of Microring-Based Hitless Reconfigurable Add-Drop Filters”. OFC San Diego, CA, 2018, pp. 1-3.

[4] Available in the PDK of AMF, Advanced Micro Foundry, http://www.advmf.com, Singapore.

[5] M. Milanizadeh, D. Aguiar, F. Morichetti and A. Melloni. “Canceling Thermal Cross-Talk Effects in Photonic Integrated Circuits,” Journal of Lightwave Technology, vol. 37 n. 4, pp. 1325-1332, 2019.

[6] M. Milanizadeh, S. Ahmadi, M. Petrini, D. Aguiar, R. Mazzanti, F. Zanetto, E. Guglielmi, M. Sampietro, F. Morichetti and A. Melloni, "Control and Calibration Recipes for Photonic Integrated Circuits," in IEEE Journal of Selected Topics in Quantum Electronics, vol. 26, no. 5, pp. 1-10, Sept.-Oct. 2020.

[7] T. Barwicz, M. Watts, M. Popovic, P. Rakich, L. Socci, F. Kartner, E. Ippen and H. Smith, “Polarization-transparent microphotonic devices in the strong confinement limit,” in Nature Photonics, vol. 1, pp. 57–60, December 2006.

[8] R. Soref and B. Bennett, "Electrooptical effects in silicon," in IEEE Journal of Quantum Electronics, vol. 23, no. 1, pp. 123-129, January 1987.