Automatic Hitless Tuning of Third Order Micro-Ring Resonator Add-Drop Filters

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ABSTRACT

The tuning and locking of a silicon photonics third order microring based filter suitable for hitless operation is presented. The filter has 8 nm Free Spectral Range (FSR) and operates in L band with a bandwidth of 42.5 GHz and isolation better than 20 dB. A novel channel labelling scheme is proposed and demonstrated to enable applications in add-drop reconfigurable architectures.

Keywords: Hitless Ring Resonator Filters, Automatic Control, Tuning, Locking.

1 INTRODUCTION

Node reconfigurability in optical telecomunication networks allows multiple data carrying wavelengths to be added and/or dropped from a communication system. Such functionality is a mandatory feature for capacity growth and management of core networks, 5G back-haul networks, optical interconnects and datacenters. Moreover, reconfigurable optical networks are based on the premise that newly provisioned channels must not affect already established ones. Photonic integrated circuits (PICs) have been demonstrated as a promising technology to implement flexible and hitless reconfigurable devices for telecom and interconnect applications [1]. However, the automatic calibration and control of such architectures during their operation is still an open challenge.

In this work, we demonstrate the automatic tuning of a third-order hitless filter based on silicon photonics (SiP) coupled Micro Ring Resonators (MRR). The filter is suitable for the implementation of multichannel add-drop reconfigurable architectures. A closed-loop control layer is implemented by using integrated transparent power monitors [2], integrated thermo-optic actuators and FPGA-embedded control algorithms. To identify the desired channel within a Dense Wavelength Division Multiplexing (DWDM) comb, a novel channel labeling strategy based on the use of a pilot tone generated locally at the node site is used, enabling to tune and lock the filter with telecommunication-graded characteristics. The experimental hitless reconfiguration is demonstrated by using single polarization 10 Gbit/s and 50 Gbit/s signals.

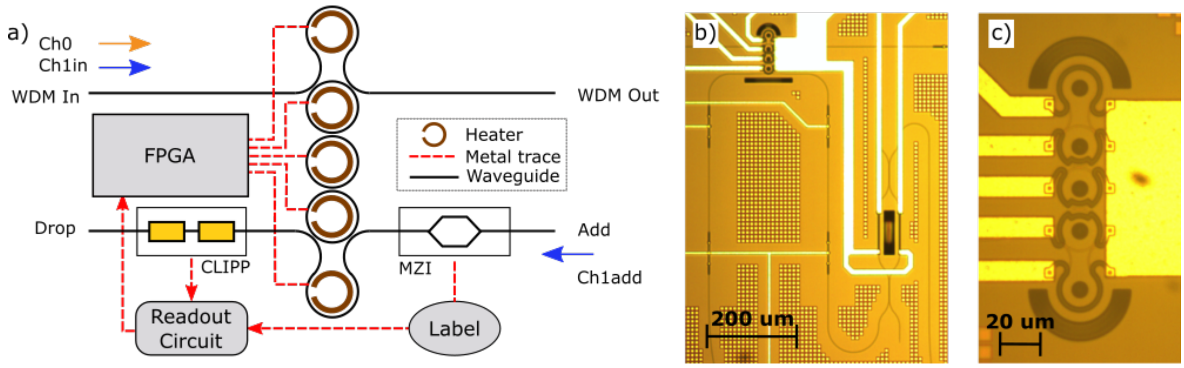

Figure 1. a) Schematic of 3rd order MRR filter with tuneable couplers in bus and add-drop waveguides, CLIPP monitor and MZ for labeling; b) micro-photograph of the 3rd order MRR filter with integrated CLIPP and labeling MZ modulator, c) detail on a 3rd order MRR filter showing heaters, waveguides, metal layer and deep trenches for heat management.

2 CHANNEL LABELING AND FILTER ARCHITECTURE

The schematic of the complete 4-ports filtering element is shown in Fig. 1a). The hitless filter consists of three directly coupled MRRs with unbalanced Mach-Zehnder (MZ) based tuneable couplers on the bus waveguides, according to the design proposed in [1]. In order to operate the filtering unit in presence of multiple DWDM channels, a weak pilot tone (channel label) is added onto the optical signal by a MZ modulator integrated on the Add port. This labeling operation is necessary to single out the Add channel from the Drop channel sharing the same wavelength. This “labeler” is typically operated at few kHz and provides an intensity modulation of few percent ($< 8\%$) that does not impair the system quality [3]. A channel label at the remote transmitter is not required and the pilot tone can be periodically switched on/off depending on the stability of the system. An all-silicon sub-band gap transparent detector (CLIPP) [2] placed at the Drop port provides the feedback error signal to be used by the control algorithms embedded in the FPGA that drives the five integrated heaters. We use the CLIPP technique and a dual demodulation scheme, as schematically shown in Fig. 1a) [3].

Fig. 1b) shows a micro-photograph of the SiP device, which was fabricated on a commercial foundry, and in Fig. 1c) a detail of the hitless filter. The silicon channel waveguide is 490 nm wide and is buried in a silica cladding. Deeply etched trenches are used to confine the heat generated by the thermo-optic actuators around the silicon waveguides in order to increase the efficiency and mitigate thermal crosstalk effects. The filter design is optimized to have 1 THz (8 nm) FSR, 40 GHz 3dB bandwidth, and 20 dB in-band isolation. The bus to ring power coupling coefficient was chosen to guarantee a good compromise between spectral characteristics and robustness to fabrication tolerances. In the fabricated device, the channel labeler is integrated on chip by using a thermally tuneable MZ modulator; however other on-chip modulators technologies, based for instance on pn-juctions, as well as off-chip modulators could be used.

The monitoring of the channel power is made with the CLIPP device already demonstrated in commercial SiP foundries. The CLIPP monitors the light intensity in a waveguide by measuring the change in the resistance of the core segment between two metal pads. This change is induced by free carrier generation, which in turn is due to photon absorption occurring in the semiconductor waveguide core. The relation between resistance variation and optical intensity depends on the number of free carriers generated by either Surface State Absorption (SSA) or Two Photon Absorption (TPA) [4].

3 AUTOMATED HITLESS TUNING

Filter tuning in presence of neighbor DWDM channels requires the filter to be optically disconnected from the bus to prevent impairments on the other channels. This operation is usually named hitless channel tuning. In our device, hitless operation is achieved by simultaneously switching both MZ tuneable couplers connecting the filter to the line bus and to the add-drop bus, respectively.The process of decoupling, tuning and recoupling can be decomposed in four steps: switching off both tuneable couplers, tuning both rings and MZs using a look-up table (LUT), switching on both tuneable couplers and finally performing automatic continuous tuning of the filter.

The filter unit shown in Fig. 1a) can be cascaded with other units to realize a multichannel reconfigurable add-drop architectures operating on several wavelengths at the same time and the various units can be used independently one from the others. The weak pilot tone is strategical to recognize the Add channel from the Drop one, since they share the same wavelength. Moreover, it permits to tune the filter optimizing the match of the filter spectral transfer function with respect to the channel spectral shape.

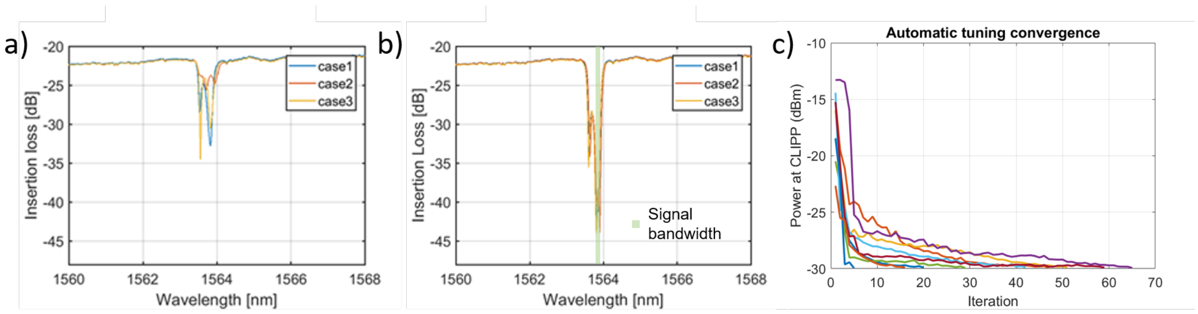

Figure 2. a) initial random spectral responses of the filter, b) tuned response of the filter and c) convergenge of the tuning algorithm.

To demonstrate the operation of the filtering unit we show that our algorithm is able to tune the filter to the wavelength of a labeled added channel and adapt its shape around the desired channel spectral shape. The automatic tuning algorithm makes use of an original transformed coordinate method [5] to tune and lock the MRRs. With this technique, the thermal phase controller of all the MRRs are tuned simultaneously at each iteration of the algorithm to minimize the target error function, which in this case is the label power at the CLIPP. A channel centered at 1563.9 nm, is split in two parts: the first one, which is provided at the Add port, has to be directed to the ”WDM Out” port of the filter unit; the second part, after being decorrelated by several kilometers of fiber, is coupled at the ”WDM In” port and has to be dropped from the Drop port. Filter tuning is performed automatically: the tuning algorithm exploits the pilot tone on the labelled channel to discriminate it from the other channel at the ”WDM In” port, brings the filter at the wavelength of 1563.9 nm, and keeps it locked. The spectral response of the automatically tuned filter is shown in Fig. 2b). As the bandwidth of the signal is much narrower than the filter, a very deep notch is created in the filter response at the expense of a slightly lower isolation at the band edges.

The power monitored by the CLIPP at the Drop port is shown in Fig. 2c).Note that only a small portion of added channel arrives at the Drop port, about 20 dB below the input power, corresponding to the isolation of the filter. For every tested starting condition the filter locking converge in few tens of iteration, each one corresponding to around 0.1 seconds.

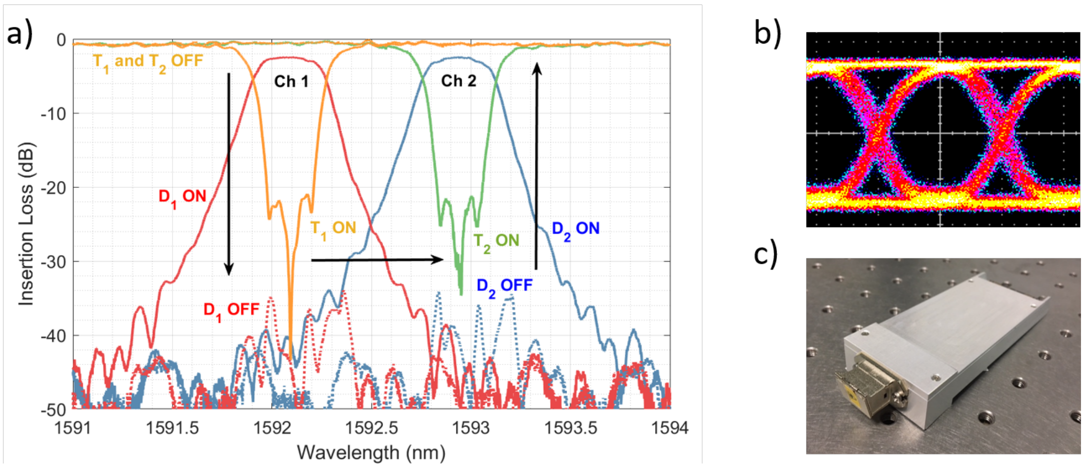

Figure 3. a) Experimental results of the hitless reconfiguration of the filter, b) eye diagram of the Ch.0 during the hitless reconfiguration of the filter and c) optical chip and control electronics assembled in a CFP2 package.

To evaluate the filter performance in the L band the filter is initially configured to Ch. 1 at 1592.1 nm (curves "D_1 ON" and "T_1 ON" Fig. 3a)), being the "WDM In to Drop" and "WDM In to WDM Out" spectral response, respectively. The tuning procedure starts with the detuning of the two MZs based tuneable couplers in order to isolate the filter from the line bus. The curve "D_1 OFF" is the spectral response between the ports "In" and "Drop" after this step, giving more than 35 dB of isolation. Next the controller is free to modify the MRRs and MZs working points without impacting other channels. Thus, the second step consists of using a pre-calculated LUT to change the voltages of the heaters corresponding to the desired channel (Ch. 2. at 1592.9 nm). Fig. 3a) shows the spectral measurements related to this steps in curves "D_2 OFF" and "T_1 and T_2 OFF ". As third step, both tuneable couplers are connected to the bus and the filter is automatically tuned to Ch. 2. The spectral response of the tuned filter is centered around Ch. 2 with an in-band isolation > 20 dB ("T_2 ON") and off-band isolation > 25 dB ("D_2 ON") at 50 GHz spacing from the central wavelength. Thanks to the high off-band rejection (more than 25 dB at 50 GHz from the center wavelength), the filter does not impact on the 50 GHz spaced channels. It should be noted that the filter tuning between two adjacent channels is the worst case; therefore similar, or even better, performance can be achieved for largely spaced channels.

To evaluate the effectiveness of the hitless tuning a reference channel (Ch. 0) centered at the wavelength 1592.5 nm is transmitted from the "WDM In" and "WDM Out" ports of the unit during the tuning procedure. The eye diagram of Ch. 0 was monitored and is shown in Fig. 3b). It remains almost unchanged during the tuning of the filter, demonstrating that hitless tuning can be performed. As shown in Fig. 3c) the optical chip and all controling electronics were assembled in a CFP2 package.

4 CONCLUSIONS

In this paper a hitless filtering unit suitable to be exploited in reconfigurable add-drop network nodes has been evaluated. We demonstrated the automatic tuning of a hitless reconfigurable silicon filter operating on 50-GHz-spaced DWDM channels in the L band. The control technique used is embedded in a FPGA to suit integration needs for high capacity networks, compact enough to possibly be packaged in a pluggable device. In addition, the filter unit can be cascaded with other units to realize a multichannel reconfigurable add-drop architecture operating independently on several wavelengths at the same time.

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