Coarse Wavelength Division Multiplexer on Silicon-On-Insulator for 100 GbE

S. Dwivedi[1], P. De Heyn[2], P. Absil[2], J. Van Campenhout[2] and W. Bogaerts[1,3]
[1]Photonics Research Group, Ghent University-imec, Department of Information Technology
Center of Nano- and Biophotonics (NB-photonics), Ghent, Belgium
[2]IMEC, Kapeldreef 75, Leuven, Belgium
[3] Also with: Luceda Photonics, Noordlaan 21, 9200 Dendermonde, Belgium
Email: sarvagya.dwivedi@intec.ugent.be

***Abstract*—A four-channel cascaded MZI based de-multiplexer at O-band with coarse channel spacing of 20 nm and band flatness of 13 nm is demonstrated on silicon-on-insulator. The device shows a mean crosstalk and insertion loss below -16 dB and 2.5 dB.**

Keywords*—Silicon photonics, wavelength filtering devices, wavelength division multiplexing.

I. Introduction

100 Gigabit Ethernet (GbE) has recently been standardized to meet the increasing demand of data centers. Silicon photonics shows a lot of potential to cater this increasing demand [1], using integrated wavelength division (de-) multiplexers (WDM) filters. There are different types of WDM filters that qualify for this (de)multiplexing function, either based on finite impulse response (FIR) filters such as array waveguide gratings (AWGs), planar concave gratings (PCGs) and Mach-Zehnder Interferometers (MZIs), or based on infinite impulse response (IIR) filters such as ring resonators. The major challenges in silicon-on-insulator (SOI) WDM filters are to keep the loss of device low and minimize the wavelength shift response when there is fabrication variations and environment temperature fluctuations.

There are different methods proposed to maximizing the fabrication and thermal tolerances of filters such as passive compensation [2] or flattening the channel pass band responses [3]. Passive compensation is sometimes limited by narrow bandwidth responses due to the use of different waveguide widths or polarization. Channel band flattening in pass bands is possible in different FIR based filters like AWGs but often comes at the cost of additional losses [4]. Ring-based IIR filters are not ideally suited for coarse WDM (CWDM) applications where channels are usually spaced 20 nm apart, due to their inherently narrow bandwidth [5].Keeping in mind the maximum channel insertion loss of 3.5 dB imposed by the 100GbE standard [1], the cascaded MZI based (de-) multiplexers appear to be the best suited option for a passive filter designed for the CWDM wavelength grid. By cascading multiple MZIs, the pass band can be engineered while keeping the device quite compact. A cascaded MZIs based approach was proposed for WDM applications [3] but is not immediately applicable for CWDM due to a narrow bandwidth design. Our proposed design is a four channel flat band CWDM with 20 nm channel spacing and channels centered at ITU grid wavelengths of (1271, 1291, 1311 and 1331 nm).

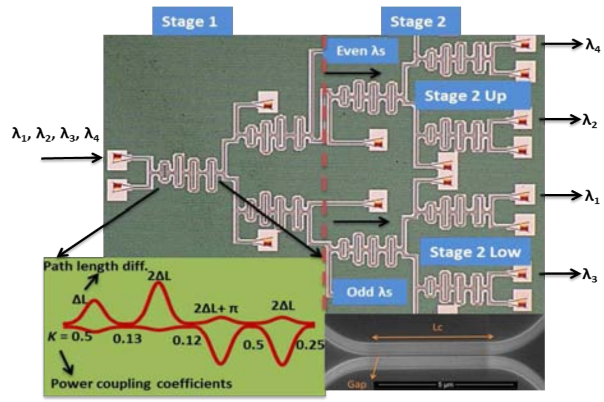

Fig. 1. Camera image of fabricated 4-channel dual stage cascaded MZI de-multiplexing filter (Inset: sketch of basic block showing ΔL, k and SEM image of one of the directional coupler showing gap and coupling length)

II. Design and Fabrication

The basic block of the de-multiplexer (de-mux) is a set of four cascaded MZIs designed to get a maximally flat response for a given free spectral range (FSR). The coupling coefficient calculations are based on FIR optical half-band filters [6]. The FSR of the individual MZIs in a basic block is inversely proportional to the delay length ($FSR = \lambda_c^2/(n_g.\Delta L)$), where λ_c is center wavelength, ΔL is the physical path length difference between longer and shorter arm of the MZI and n_g is group index of the designed waveguide.

The de-mux is divided into two stages, and each stage consists of two cascaded MZI blocks. The first block is designed as an interleaver, and splits the odd and even wavelength channels. The two outputs are then sent to a second block that enhances the suppression of the unwanted wavelengths. The first stage is centered at 1301 nm and each MZI at this stage is designed for a free spectral range (FSR) of 40 nm. The second stage is designed in a similar fashion as the first stage, but with an FSR of 80 nm and therefore the designed ΔL needed is half that of the first stage. The second stage splits the 2×2 interleaved wavelength channels into four separate waveguides. The camera image of fabricated design and the basic cascaded MZIs block with power coupling coefficients are shown in Fig. 1. The coupling coefficients are the same for all stages, but the center wavelengths are tuned for each individual stage. Physically this means that the directional

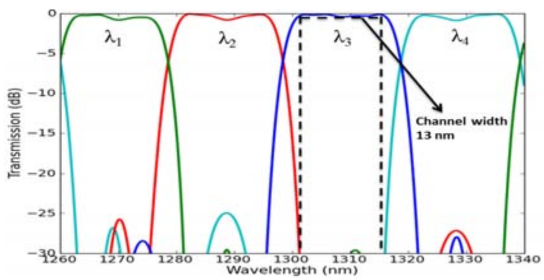

Fig. 2. Simulated transmission of the de-mux filter

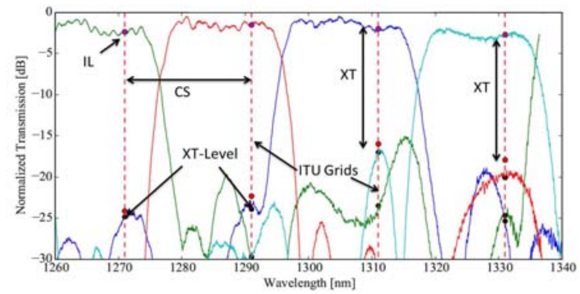

Fig. 3. Measured transmission of the de-mux filter showing channel spacing (CS), insertion loss (IL) and crosstalk (XT) at ITU grid wavelengths

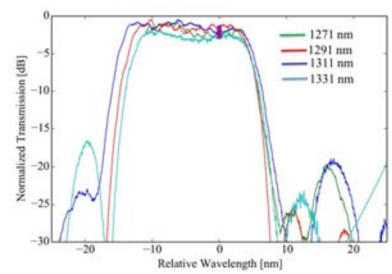

Fig. 4. The normalized transmission shown in function of the relative wavelength around the ITU grid, showing a good channel uniformity

couplers (DCs) are adjusted for the designed wavelengths for individual stages by changing the coupling length with a fixed gap. The π phase shift in the basic cascaded MZIs block is given by $L_\pi = \lambda_c/2.n_{eff}$, where n_{eff} is effective index of the waveguide at λ_c . Similar calculations are performed to provide the phase shift of $\pi/2$ in stage 2-low or odd channels to adjust the center wavelengths of output channels.

The device is designed in the IPKISS parametric framework and fabricated in IMECs standard passive platform. This process uses 200 mm SOI wafers with 220 nm of silicon and 2 μm of buried oxide. The device is designed for TE polarized light with oxide as the top cladding. To ensure single mode operation the delay lines are fabricated with 380 nm wide waveguides and the same widths are used in DCs, which have a gap of 150 nm. The total footprint of the device is $550 \times 650 \mu m^2$.

III. Simulation and Measurements

The waveguide and directional coupler simulations were performed in the full wave solver COMSOL. The full device simulations were performed in circuit simulator Caphe [7] taking waveguide dispersion and wavelength dependence of the directional couplers into account. The device simulation is shown in Fig. 2.

The transmission measurements of the device are performed with a CW O-band tunable laser. The spectral response of the fiber grating coupler at the input and output of filter are removed from the measured spectrum using a reference waveguide in order to analyze the filter response. The normalized spectrum of the device is shown in Fig. 3. The channel spacing (CS) matches well with the 20 nm specifications; the ITU wavelengths are indicated by a dashed line. The measured 1 dB channel bandwidth of all channels is more than 12nm, or over 60 percent of the channel spacing. This band flatness helps in handling the temperature changes of 100 °C at the transmitter and receiver side.On-chip device insertion loss (IL) is calculated by normalizing the spectrum to that of a reference grating coupler and the mean value is less than 2.5 dB at the ITU wavelengths. Channel crosstalk (XT) is defined as the total power that one channel gets from the other channels, at a given wavelength, and relative to the IL. Channel 1 is performing the best with XT below -22 dB and channel 4 is worst with XT below -14 dB. The device mean value is below -16 dB. The reason for this increasing XT towards longer wavelengths is the strong wavelength dependence of the directional couplers.

To visualize the channel uniformity, the 4 channels are shifted on top of each other based on ITU grid. This is shown in Fig. 4 where the normalized transmission is shown in function of the relative wavelength around ITU grid. The device shows good channel uniformity and mean 3 dB and 10 dB channel bandwidths of 17.4 nm and 21.38 nm respectively.

IV. Conclusion

We demonstrate silicon-on-insulator four-channel de-mux filter with a 20 nm of channel spacing designed to match the CWDM ITU grid at O-band. Wide band flatness and low loss makes this filter a good candidate for 100 GbE and 400 GbE applications. This work is supported by IMEC Optical IO program.

References

[1] Y. Vlasov, "Silicon cmos-integrated nano-photonics for computer and data communications beyond 100g," *Communications Magazine, IEEE*, vol. 50, no. 2, pp. s67–s72, February 2012.

[2] S. Dwivedi *et al.*, "Maximizing fabrication and thermal tolerances of all-silicon fir wavelength filters," *Photonics Technology Letters, IEEE*, vol. 27, no. 8, pp. 871–874, April 2015.

[3] F. Horst *et al.*, "Cascaded mach-zehnder wavelength filters in silicon photonics for low loss and flat pass-band wdm (de-)multiplexing," *Opt. Express*, vol. 21, no. 10, pp. 11 652–11 658, May 2013.

[4] S. Pathak *et al.*, "Optimized silicon awg with flattened spectral response using an mmi aperture," *Lightwave Technology, Journal of*, vol. 31, no. 1, pp. 87–93, Jan 2013.

[5] P. De Heyn *et al.*, "Fabrication-tolerant four-channel wavelength-division-multiplexing filter based on collectively tuned si microrings," *Lightwave Technology, Journal of*, vol. 31, no. 16, pp. 2785–2792, Aug 2013.

[6] K. Jinguji and M. Oguma, "Optical half-band filters," *Lightwave Technology, Journal of*, vol. 18, no. 2, pp. 252–259, Feb 2000.

[7] M. Fiers *et al.*, "Time-domain and frequency-domain modeling of nonlinear optical components at the circuit-level using a node-based approach," *J. Opt. Soc. Am. B*, vol. 29, no. 5, pp. 896–900, May 2012.