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Fabrication Tolerant Flattened Wavelength Division Multiplexers for 100GbE on 200mm Silicon-On-Insulator platform

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Abstract

We investigate numerically and experimentally 100GbE LR4 and CWDM4 wavelength division multiplexers based on cascaded Mach-Zehnder with enhanced robustness regarding fabrication variations. The measurements show a clear improvement of the channel stability over the 200mm wafer for both O-band norms.

1. Introduction

The progress of silicon photonics towards its generalization into datacom products is still limited by some practical problems. Beyond the run for the best integrated laser source, the reliability and reproducibility of silicon-on-insulator (SOI) optical devices remain a key point, even for passive structures studied for decades now. The fabrication variations due to the SOI wafer thickness dispersion [1] and lithography [2] uncertainty impact directly the phase and propagation constants of the optical modes for any type of waveguide. In this context, the development of wavelength division multiplexing (WDM) circuits can be extremely challenging since most of the passive functions are made by refractive based optical devices (ring resonators, directional couplers, AWGs, MZIs) very sensitive to phase shifts [2], in contrast to diffractive component intrinsically more robust [3]. The spectral drifts are usually compensated by a thermal control at the expense of higher power consumption. For multiplexers (MUX), the flattening of the channels can advantageously increase the operational bandwidth for a larger acceptable temperature range [5, 6, 7].

In this contribution we study numerically and experimentally two types of MUX for both 100GB-Ethernet LR4 (ITU-T G.694.1) and CWDM4 (ITU-T G.695) grids. These advanced optical half-band filters [8] were designed with both flattened channels to increase their tolerance to temperature fluctuations [7] and an asymmetric design of the confinement factors of each Mach-Zehnder bloc [9] in order to enhance simultaneously the fabrication tolerance.

2. Robust flattened MUX design

The optical bandwidth of MZIs MUX can be stretched by increasing each lattice filter order [8]. However, the resulting flattening remains sensitive to fabrication variations. Thus we followed first a method previously used for athermal MUX [10] that can be transposed to reduce process variations of MZIs using two different waveguides on the interferometer arms [9]. In this work, we focalized our optimizations on the rib waveguide width variations to decrease the sensitivity of the MZIs from 210pm/nm to less than 20pm/nm. By doing so, the tolerance to the etching was also improved by a factor of 4 in our case. These robust MZIs were subsequently used as elementary element for several 3rd, 5th, and 7th orders half-band filters for LR4 and CWDM4 norms using a commercial transfer matrix tool [11] and genetic algorithm for the coupling coefficients calculations. The MUXs were fabricated on CMOS 200-mm pilot lines starting from 300nm thick SOI substrates with a single DUV lithography step followed by an HBr-based reactive ion partial etching of 150nm for the silicon rib waveguide patterning, prior to a 1µm thick silica high-density plasma deposition for the encapsulation.

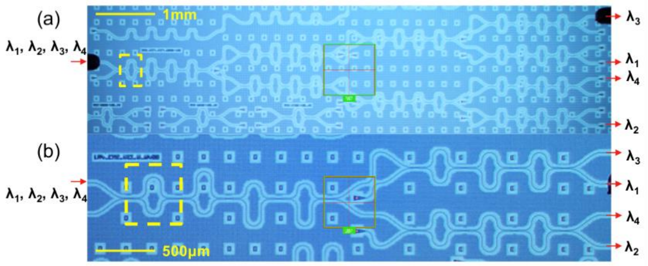

Fig. 1 Optical image of 100GbE MUXs for (a) CWDM4 and (b) LR4 norms. The yellow dotted frame shows a single MZI footprint.

The Fig. 1 shows the optical images of CWDM4 and LR4 cascaded MUX. The first one consists of 36 MZIs in line divided in 4 half-band filter groups [7]. The second MUX uses less MZIs (10) since the filtering is concentrated on a shorter bandwidth (800GHz spacing). Next the transmission spectra were measured on a 300mm fiber-to-fiber prober, and then normalized we reference test lines, as illustrated in the Fig. 2.

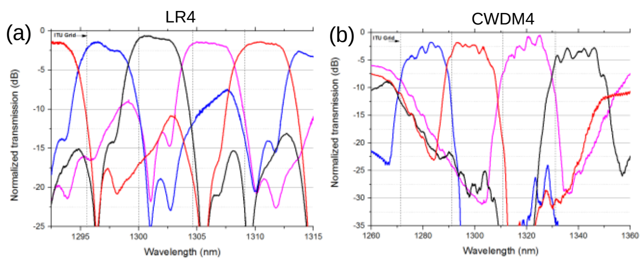

Fig. 2 Normalized transmission spectra of the (a) LR4 and (b) CWDM4 MUXs. The vertical dotted lines represent the ITU grids.

For the LR4 device (Fig. 2 (a)), we found insertion losses below 2.5dB for more than 2.5nm bandwidth for the 4 channels and a crosstalk range between 7.5 to 15dB. The CWDM4 transmission spectra of the Fig. 2(b) appears more noisy but still shows respectable insertion losses below 5dB over a 13 nm bandwidth for all the channels and a crosstalk between 10 to 25dB at the center of the channels.

3. Wafer level robustness

The optical properties being characterized, we study next the stability over a 200mm wafer for both LR4 and CWDM4 MUXs. The Fig. 3 provides a comparison between a classical cascaded MZI LR4 filter and the robust version by plotting the transmission spectra of 8 dies, only for a single channel for more clarity.

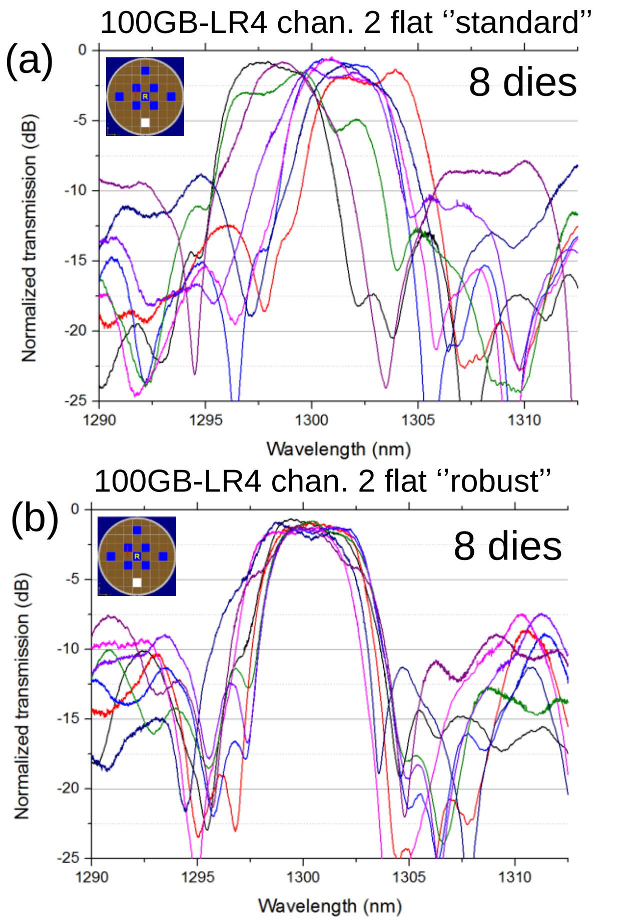

Fig. 3 Normalized transmission spectra over 8 dies (see inset) of (a) standard cascaded MZI MUX and (b) robust version for the LR4 channel 2 (centered on 1300.05nm).

For the standard design (Fig. 3 (a)), even though the channel were flattened, the dispersion over the wafer can be clearly observed with a spectral drift of +/- 2.5nm, as large as the -1dB bandwidth. On the other hand, the robust design offers a stable -1dB bandwidth greater than 2nm for all the superposed dies. Finally, we characterized in the same way the reproducibility of the robust CWDM4 MUX over 9 dies on the exact same wafer as the LR4, as shown in the Fig. 4. Despite the general red shift and the fluctuations on the top of the channels, we observe again a great stability of the filtering pattern for each channel (13nm bandwidth between -5 to -7.5dB insertion losses).

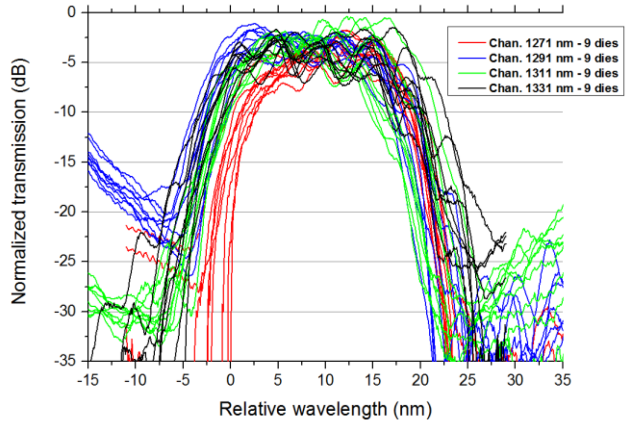

Fig. 4 Normalized relative transmission spectra over 9 dies for the 4 channels with respect to the CWDM4 ITU grid center.

We expect that the top channels oscillations can be cleaned with broadband grating couplers and eventually with smoother bends and directional couplers, stabilizing furthermore the operational windows below -2.5dB for the same bandwidth. Moreover, the red shift observed for this first generation of CWDM device can be also easily corrected with a more precise determination of the effective and group index of our platform, for instance by taking into account the residual silicon nitride hard mask.

4. Conclusions

In summary, a detailed approach for the design of high robustness CWDM4 and LR4 multiplexers has been given. The fabrication tolerance of the filters was improved by a precise quantification of the MZI waveguide width sensitivity and implemented in series to increase the channels bandwidth and provide a stable and large temperature operational range. The crosstalk of the LR4 and insertion losses of the CWDM4 must still be improved to match the respective norm requirements.

Acknowledgements

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