Statistical analysis of passive components manufactured in a thick silicon nitride platform

(Student Paper)

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ABSTRACT

In this paper, the statistical analysis of the measurements of passive components manufactured in a thick silicon nitride platform is presented. The devices studied are Asymmetric Mach-Zehnder interferometers (AMZI) and 1x2 and 2x2 Multimode Interference Couplers (MMI). Components from four different Multi-Project-Wafer runs [1], have been designed, manufactured and tested. Each run yielded two wafers and two dies per wafer have been measured and reported. The Asymmetric Mach-Zehnder interferometers were used to evaluate the propagation parameters of the strip waveguides employed in the designs. These parameters are: the propagation losses, the modal effective index and the group index. The multimode interference couplers (MMI) have been employed to evaluate the fabrication tolerances. By collecting and evaluating this statistical data across multiple dies, wafers and runs we have concluded that the designs evaluated are robust and the manufacturing process is stable within the tolerances provided by the foundry. This is fundamental for high-volume, high-yield commercial applications for future market developments in thick silicon nitride platforms as quantum, comb generations, LIDAR systems, etc.

Keywords: thick silicon nitride, silicon nitride, yield, manufacturing.

1. INTRODUCTION

Photonic devices performance is very sensitive to geometrical variations in the mid/high index contrast platforms. These variations have a direct impact on the spectral response of the different building blocks and it requires an in-depth statistical analysis of the manufactured and tested devices. The increasing of photonic integrated market demands fabrication tolerant building blocks and an extensive yield analysis [2-3]. Thick silicon nitride is a promising technology due to its intrinsic properties as anomalous dispersion in C band, low loss for TE and TM polarizations, compactness, low bending radius and operation from visible to mid infrared band [4].

Different techniques are employed in the fabrication of photonic integrated circuits (PICs) to physically evaluate the geometrical definition of the waveguides composing the circuits. From Critical-Dimension Scanning Electron Microscopy (CD-SEM) in the lithography tools to post fabrication analysis with Atomic Forces Microscopy (AFM). In this work, the optical characterization of interferometric devices [5] is employed to derive the fabrication deviations in the waveguides of a thick silicon nitride platform.

2. MZI measurements

The Free Spectral Range (FSR) and the resonance wavelength of an AMZI are related to the effective and group index of the waveguides through the formulae:

$$\lambda_{res} = \frac{n_{eff0} \cdot \Delta L}{m}, \qquad FSR = \frac{\lambda_{res}^2}{n_g \cdot \Delta L}$$

Being m the order of MZI resonance, λ_{res} the central wavelength of the resonance, n_{eff0} the effective index at this wavelength, n_g the group index of the waveguide, ΔL the incremental length of the waveguide and FSR the distance in nanometers between two adjacent resonances. With a combination of different order AMZIs the effective and group indices of their waveguides can be accurately obtained [5].

A test cell has been designed, manufactured and characterized in 4 different Multi Project Wafer runs in the Ligentec platform employing the PDK co-developed with VLC Photonics [1]. The standard test die has a size of 5x10 mm². Several 1x2 and 2x2 multimode interference couplers (MMIs) and AMZIs employing the 2x2 MMI couplers with FSRs of 8, 12 and 20 nm have been included in the test cell for every run. The measurements of the MMIs show a broadband operation with low imbalance and the MZI devices show in some cases more than 40 dB of rejection ratio. In general, the performance of the components is in good agreement with the simulations.

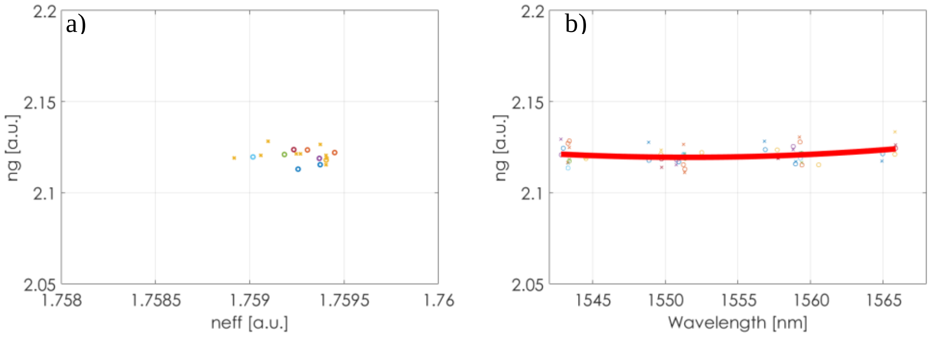

Figure 1. (a) N_{eff} vs n_g at 1550 nm, (b) n_g vs wavelength measured

Figure 1-(a) shows the effective index versus group index at 1550 nm wavelength. The mean value of the effective index is 1.75925 ± 2.5e-4. In figure 1-(b), the group index versus wavelength is plotted. The mean value is 2.119 ± 9e-3. It can be observed that the group index variation is larger due to the fact that there are a small number of points in wavelength. This can be solved by having an AMZI device with a smaller FSR.

TABLE 1. Comparative of n_g, n_{eff} and incremental length

FSR	Sim. n_g [a.u]	Sim. n_{eff0} [a.u.]	ΔL [µm]	m [a.u]	Meas. n_g [a.u]	Meas. n_{eff0} [µm]
20	2.1166	1.7585	56.744	64	[2.11-2.128]	[1.7589-1.7594]
12	2.1166	1.7585	94.590	107	[2.11-2.128]	[1.7589-1.7594]
8	2.1166	1.7585	141.88	160-161	[2.11-2.128]	[1.7589-1.7594]

Table 1 includes a comparison of simulated and measured effective and group indices of the manufactured MZIs. The standard deviation of the measured values matches perfectly with the expected shift in the indices due to the fabrication tolerances according to the foundry process. A remarkable observation of the data is the shift of effective index in median of about 5e-4. To investigate this shift, an extensive set of simulations were performed sweeping over different waveguide widths and heights. A model for the effective and group indices has been developed to fit the indices as a function of waveguide widths and heights.

$$n_{eff}(1550nm) = 1.285 + 0.5099 \cdot w + 0.1472 \cdot h - 0.1883 \cdot w^2 + 0.04167$$
$$n_g(1550nm) = 1.964 + 0.2078 \cdot w + 0.1167 \cdot h - 0.0833 \cdot w^2 - 0.0833 \cdot w$$

From the model obtained, it can be derived that an increase in width of 50 nm or an increase in the height of 12 nm can explain this shift of the effective index.

2.1 MMI 1x2 and MMI 2x2

MMIs are fabrication tolerant devices when compared to other power splitters [6-10]. Figure 2 shows the response across eight wafers and sixteen dies from four different fabrication runs (two wafers per run, 4 dies measured per wafer) of the imbalance and the excess losses calculated from the transmission measurements.

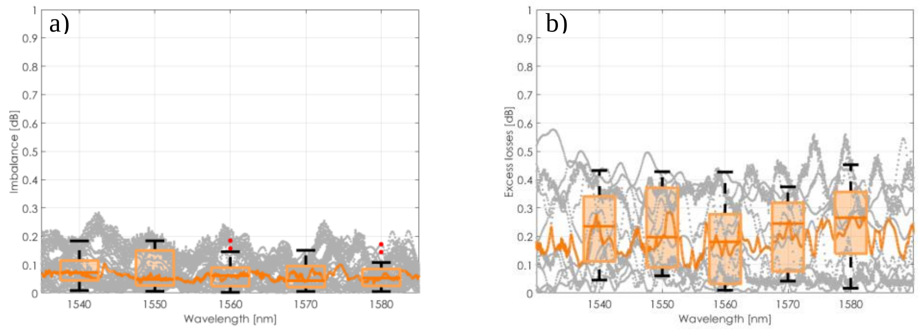

Figure 2. MMI 1x2 (a) imbalance and (b) excess losses

The median of imbalance, as shown in Fig. 2-(a), is below 0.1 dB and the median of the excess losses is kept below 0.3 dB as depicted in Fig. 2-(b) for the 60 nm wavelength range under study.

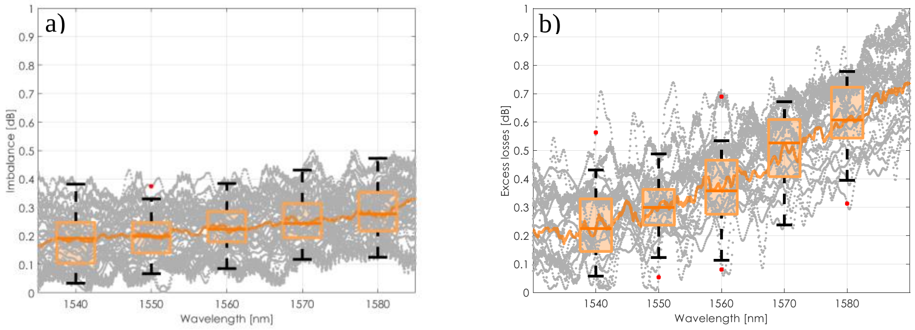

Figure 3. MMI 2x2 (a) imbalance and (b) excess losses

Figure 3 provides imbalance and excess losses versus wavelength for MMI 2x2. Interestingly, the imbalance median is below 0.3 dB in the wavelength range evaluated. The most striking observation is that the minimum of the excess losses is centered below 1530 nm. An analysis of the MMI simulations showed that a deviation of 50 nm in width could explain this shift in the minimum peak value of the excess losses that has to be around 1550 nm. With this information we have been able to conclude that if the MMI is shortened 2 microns in length, the excess losses response will improve at 1550 nm wavelength.

3. CONCLUSIONS

The statistical study of the basic building blocks measurements, designed and fabricated in a thick silicon nitride platform has been performed to evaluate the impact of the process variability in the components performance. A theoretical model for the effective and group index of the silicon nitride waveguides has been employed to correlate the measured data with the waveguide width and height deviations expected from the fabrication process. With the analysis of the measurement data of the 1x2 and 2x2 MMIS we have demonstrated the robustness of the designs against the variation tolerances of the fabrication platform. This statistical analysis can be employed to improve the design of the components.

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