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Deep Rib and new Thin Rib High Speed Phase Modulators Optimization on 300mm Industrial Si-Photonics Platform for 400G applications

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Abstract

This paper highlights the optimization of High Speed Phase Modulators (HSPM) for 400G applications fabricated on our 300mm photonic platform. The paper presents our most optimized modulators obtained after a large Design of Experiments (geometries & implants) to obtain the best optical vs speed results. Results show Deep Rib HSPM with 1,2dB gain in OMA (Optical Modulation of Amplitude) with improved cutoff frequency (fc=[2Pi*RC]$^{-1}$) by 15% compared to the previous generation [Ref 1]. In addition, we propose a new Thin Rib HSPM structure, allowing 40% of capacitance reduction by reducing Si thickness of the modulator from 300nm down to 150nm, leading to 35% gain in speed.

Keywords—photonics, Deep Rib PN junction modulators, Thin Rib PN junction modulators.

1. Introduction

Silicon photonics technology provides unreached data densities and integration level while taking benefits from low cost and industrial manufacturing infrastructure of CMOS electronics [1]. In this paper, O-band Silicon PN junction modulators have been designed and integrated taking advantage of the co-integration of a 50nm thick slab (deep rib). In order to improve light confinement in the core for maximizing the modal overlap with PN junction, we first optimized a Deep Rib architecture with optimized implants and structure thanks to a DOE (Design Of Experiments) analysis, and we propose for the first time a new Thin Rib HSPM structure with optimized geometry and implants to reduce the device capacitance by 40%.

2. DOE devices integration for deep rib HSPM

A Design Of Experiments (DOE) for Deep Rib modulators was tested on our 300mm Si-Photonics platform DAPHNE [2], including Ge Photodiodes, 310nm thick Si & 600nm/350nm thick SiN waveguides and transitions for CWDM circuits.
This DOE includes variations on the junction position Xj wrt the center of the waveguide (from 40nm to 100nm), on the width of the modulator (Width, from 280 nm to 440nm), on the distance dMOD of access arms implants to the guide (dMOD, from 200nm to 400nm) and on the deep rib width (dSD2, from 0,3 to 1,7µm, see fig.1). All HSPM devices benefited also of high level of access Arms implants (x20 higher dose vs reference platform [1]). The objective was to optimize both optical performances and access resistances to improve the cut-off frequency. Fig. 2 presents the static loss (dB/mm) vs the phase shift (°/mm) @1,8V measured for the complete DOE of the Deep Rib modulators. The optimum devices correspond to the best trade-off of phase shift for the lowest static losses. Compared to previous work [3], we optimized dSD2 parameter and access arms implants to decrease the access resistance and continue to improve the cutoff frequency by 15% compared to previous industrial platform. Results are showed on fig.3.

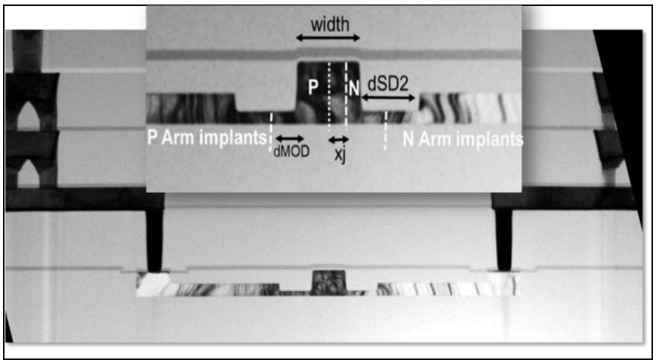


Fig. 1 -TEM X-section of final HSPM structure. DOE Parameters: junction position Xj (from 40nm to 100nm), width of the modulator (width, from 280 nm to 440nm), the distance dMOD of access arms implants to the guide (dMOD, from 200nm to 400nm) and the deep rib width (dSD2, from 0,3 to 1,7µm).

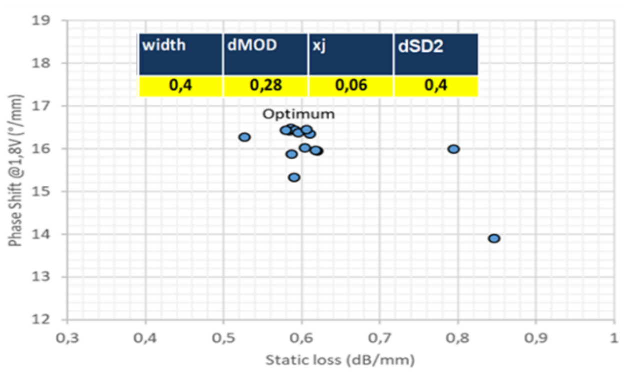


Fig.2 -Results of the DOE: Phase shift vs Static Loss explored for all geometries (each point=average values for all measured dies). The optimum is obtained for highlighted parameters. V=1,8V.

We calculated the OMA value for the optimum structures of the DOE. OMA is defined as the difference between the optical power levels (*Phigh* and *Plow*) of the signal. The value of OMA is calculated based on the extracted HSPM parameters: α=total device Losses (dB/mm), PS=device Phase Shift (°/mm) and L=device length (mm). Access resistance R was obtained with calibrated TCAD simulations, while other parameters (capacitances, losses, phase-shift) where measured on the fabricated devices.

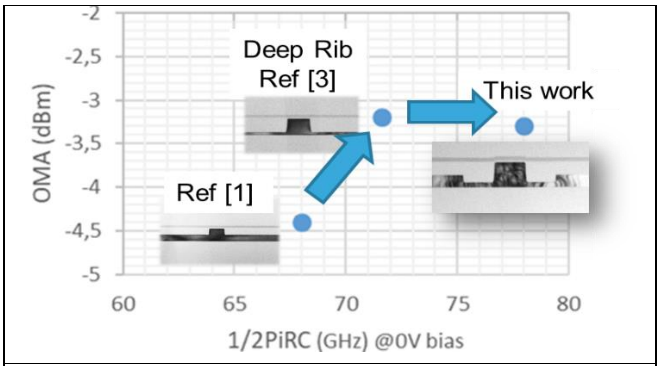
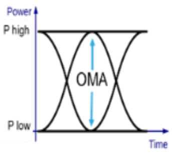


Fig.3 -Optimized HSPM structure from the experimental DOE. 1,2dB gain in OMA and 15% speed increase is obtained vs standard Rib of reference [1]. OMA is calculated for L=2,4mm.

$$OMA\ (dBm) = 10.Log_{10}(Phigh - Plow)$$

$$Phigh = 10\hat{}\left(\frac{-\propto.L}{10}\right).cos^2\left(\frac{\pi}{4} - \frac{PS.L}{180}.\frac{\pi}{2}\right)$$

$$Plow = 10\hat{}\left(\frac{-\propto.L}{10}\right).cos^2\left(\frac{\pi}{4} + \frac{PS.L}{180}.\frac{\pi}{2}\right)$$



3. New Thin Rib HSPM structure

We propose in this paper a new structure for the HSPM named Thin Rib. The core of this HSPM is 150nm thick and co-integrated with the regular 310nm thick SOI waveguides. The objective is to reduce the junction capacitance with limited impact on optical performances. In this way, much higher speed is expected, and this approach can be particularly interesting for travelling wave modulators to reduce power consumption. Figure 4 shows the TEM cross section after the complete process flow. The Thin Rib approach reduces the capacitance from 410fF to 250fF (40% reduction), see figure 5. On figure 6 are presented the Phase shift in function of static loss for the best geometries to compare Standard Rib, Deep Rib and Thin Rib. Compared to the previous structures with 300nm thick Rib, the Thin Rib structure presents a similar phase shift, but slightly higher losses, due to the etching process that induces surface roughness on the top of the waveguide. This could be solved with H2 anneal to smooth the Si-surface [4]. Then we calculated OMA and cut-off frequency to compare with the standard Rib reference (for L=2,4mm). Higher speed is obtained for Thin Rib at the price of a slightly degraded OMA. Nevertheless, the expected gain in power consumption obtained with the C reduction (P≈CV²) will be consequent and of interest for travelling waves modulators.

4. Conclusions

This paper highlights the optimization of High Speed Phase Modulators for 400G applications fabricated on our 300mm photonic platform. Results show Deep Rib HSPM with 1,2dB gain in OMA with improved cutoff frequency ($fc=[2Pi*RC]^{-1}$) by 15% compared to the previous generation [Ref 1]. In addition, we propose a new Thin Rib HSPM structure, allowing 40% of capacitance reduction by reducing Si thickness of the modulator from 300nm down to 150nm, leading to 35% gain in speed.

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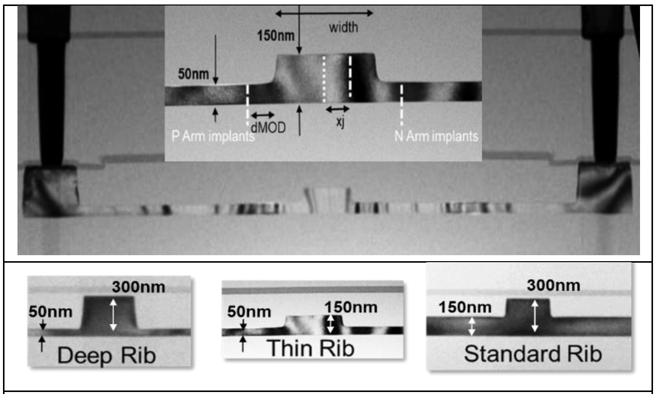
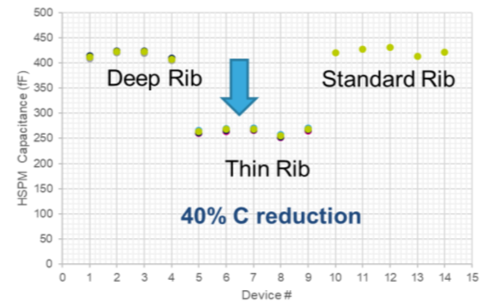


Fig. 4 -TEM X-section of the new Thin Rib HSPM, with a 150nm thick core compared to the 300nm thick Std Rib and Deep Rib.

Fig.5 -40% of HSPM capacitance reduction in Thin Rib device.



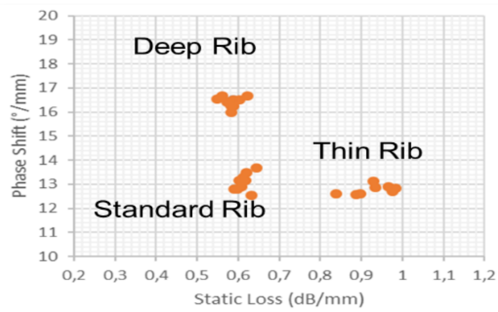


Fig.6- Comparison of Phase shift vs Static Loss measured for the best HSPM structures. V=1,8V. Optimum Thin Rib device is obtained for the following parameters: xj=0,08µm, Access arm doping distance (dMOD)=0,3µm, Device width=0,44µm.

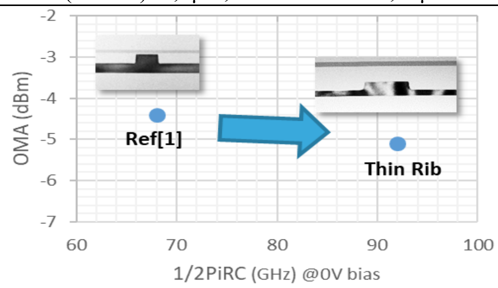


Fig.7- OMA vs Cutoff frequencies calculated for the Thin Rib and compared to reference [1].

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