B-3-03
Extended Abstracts of the 2019 International Conference on Solid State Devices and Materials, Nagoya, 2019, pp83-84

Silicon Photonics Co-integrated with Silicon Nitride for Optical Phased Arrays

Aleksandrs Marinins, Sarvagya Dwivedi, Jon Øyvind Kjellman, Sarp Kerman, Tangla David, Bruno Figeys, Roelof Jansen, Deniz Sabuncuoglu Tezcan, Xavier Rottenberg and Philippe Soussan

Imec
Kapeldreef 75, 3001 Heverlee, Belgium
Phone: +32-476-603874 E-mail: aleksandrs.marinins@imec.be

Abstract

In this work we present Si/SiN photonic build-up for beam forming applications, such as optical phased arrays (OPAs). We demonstrate low loss waveguides, vertical transitions between Si and SiN layers and efficient thermo-optical phase shifters. As a result, beam steering of a well-collimated beam is shown.

1. Introduction

Silicon-on-insulator (SOI) photonics is undergoing massive industry deployment nowadays. Si-based photonic integrated circuits (PICs) are readily acknowledged for optical communications, sensing, LiDAR and other applications [1-2]. Combining Si photonics with Silicon Nitride (SiN) expands built-up functionality by allowing power handling larger than 20W in a single waveguide, allowing development of highly efficient PICs for particular applications, such as OPAs [3]. Si brings its full flexibility for active devices like thermo-optical phase shifters, and SiN deals with high optical power modules due to no limitation of two-photon-absorption (TPA). Vertically stacked Si and SiN layers with low-loss transitions ensure high device packing density.

2. Design and fabrication process

PIC fabrication was performed at imec's 200 mm wafer fab [4]. Ready build-up is schematically depicted on Figure 1 top. Patterns of photonic layers were defined with advanced 193 nm dry DUV lithography. Si devices were patterned on standard photonic SOI wafers by dry etch, then thermally oxidized to reach 195 nm thickness with 50 nm high quality thermal oxide on top. This oxide serves as a spacer between Si and SiN layers. Resulting fully etched Si waveguide dimensions are 450×195 nm. After Si layer planarization, 400 nm thick SiN film is deposited by low pressure chemical vapor deposition (LPCVD). Ellipsometry measurement showed highly uniform wafer scale thickness and refractive index of 2.006 at 1550 nm. SiN is then dry etched to define 850 nm wide waveguides with nearly vertical sidewall profile. 3D AFM analysis shows sidewall roughness below 0.8 nm. Si-SiN layer vertical couplers are implemented by tapered waveguides (Fig. 2). Nominal tip width was 150 nm for both layers, leveraging the advantages of DUV lithography. Simulations show 99.7% coupling efficiency with only 23.6 µm device length. Next, tungsten microheaters are defined at 1 µm distance above Si waveguides forming thermo-optical phase shifters. This distance ensures heater isolation from optical mode and sufficient heat flow to Si waveguide. The wafers are metalized with 2 levels of Cu and Al pads. The Si/SiN transitions and Si/W phase shifters enable efficient thermo-optic phase shifters to be integrated with low loss, low non-linearity SiN waveguides.

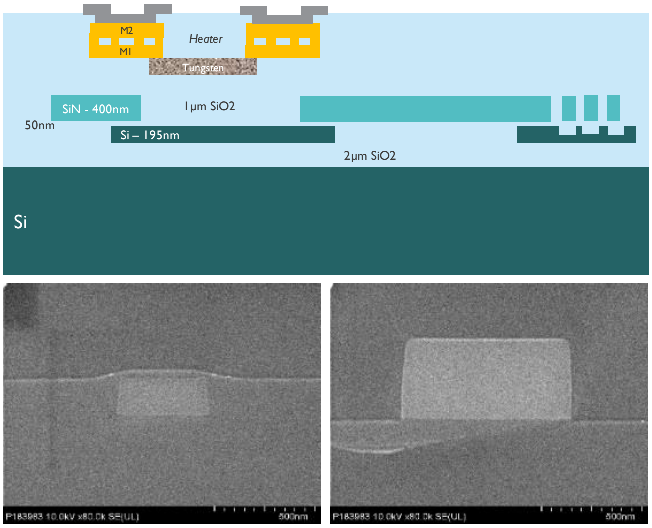

Fig. 1 Top: schematic cross section of the photonics build-up. Bottom left: Si waveguide. Bottom right: SiN waveguide.

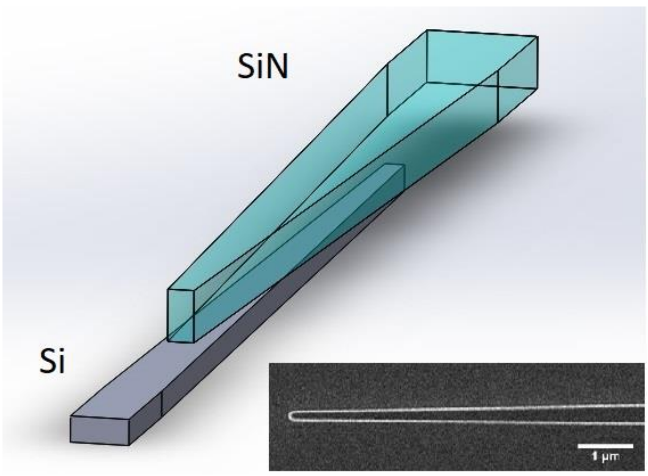

Fig. 2. Si-SiN waveguide transition schematic. Inset shows top view SEM image of SiN taper.

3. Experimental results

Wafer-scale optical measurements were performed to evaluate device performance and die-to-die variations. Waveguide propagation losses were extracted by measuring different length spirals and correlating length and insertion loss difference. Si-SiN coupler loss was extracted by measuring equal length waveguides with different count of transitions (max 640). Propagation loss data, as well as Si-SiN coupler and phase shifter loss, is summarized in table I.

Table I Waveguide and transition losses at 1550 nm

Si WG loss (dB/cm)	SiN WG loss (dB/cm)	Si-SiN coupler loss (dB)	Phase shifter loss (dB)
-1.7±0.25	-0.25±0.06	-0.06±0.01	<0.5

Obtained Si loss values are on the same level with foundries producing commercial Si photonics products. At the same time, co-integrated low loss SiN waveguides make it possible to develop large area photonics applications such as OPAs. The demonstrated build-up allows the advantages of both Si and SiN to be leveraged for photonic integrated circuits with very low layer-to-layer transition penalty.

To effectively manipulate phase in OPA, miniature and low power consumption phase shifters are of high value. The Si/W thermo-optic phase shifters integrated with SiN waveguides shown in this work are compact with a length of 254 µm including Si/SiN transitions. The phase shifters require 27 mW per π phase shift which is a quarter of the required power for pure SiN thermo-optic phase shifters.

4. Optical phased array demonstrator circuits

Combined all together, developed components are used to construct complex PICs such as OPA. The demonstrated OPA circuit consists of 64 optical antenna array fed by MMI splitter tree (Fig. 3 top). The optical antennas are 250 µm long weak grating structures, also known as leaky wave antennas (LWAs), created from Si waveguides with SiN perturbation as seen in Fig. 3 middle. The fully etched SiN perturbation allows the creation of weak LWAs while relaxing lithographic tolerances and etch control compared to pure Si LWAs. Using Si for the waveguiding structure reduces coupling between antennas. The OPA measurement has been performed using a custom-built imaging setup, where the back focal plane (BFP) of the objective (used to collect the emitted light from phased array) has been imaged on an infrared (IR) camera using a set of lenses. This allows characterization of the far-field emission pattern of the OPA. By changing input wavelength from 1530 nm to 1600 nm, outcoupled beam could be steered by ±10°.

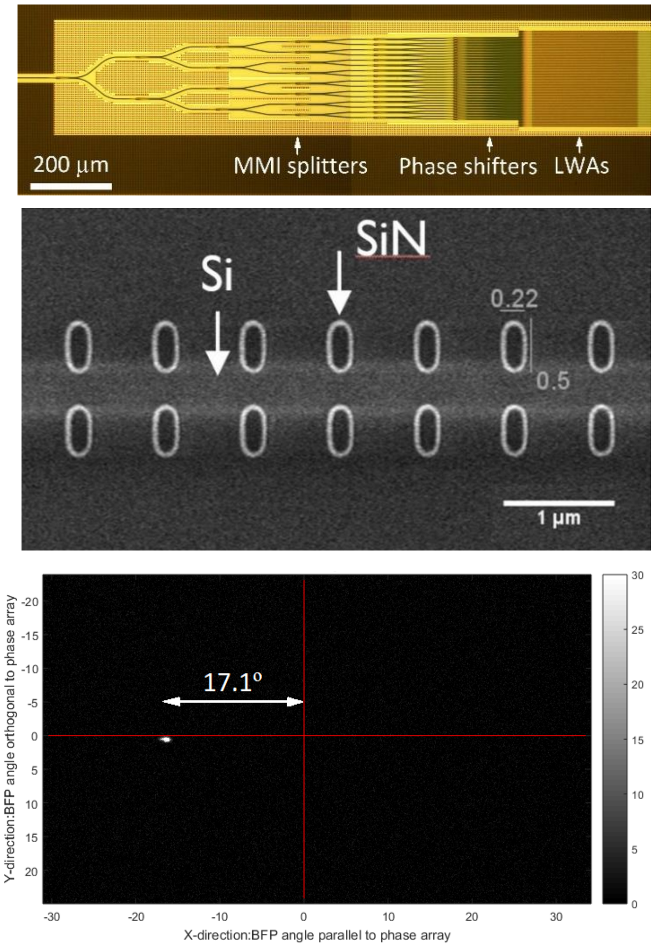

Fig. 3. OPA tree optical image (top); leaky wave antenna SEM image (middle); measured OPA far field BFP showing the beam spot, emission angle at 1550 nm (bottom).

5. Conclusions

In this work we have demonstrated a dual Si and SiN vertically stacked photonic build-up operating at C-band. A combination of high thermo-optic coefficient and index contrast Si devices and low loss SiN waveguides resulted in successful demonstration of optical beam steering with a low divergence beam.

References

[1] R. Soref, IEEE J. Sel. Top. Quantum Electron. **12**[6] (2006) 1678-1687

[2] X. Chen et al., *Proc. of IEEE,* Vol. 106[12] (2018)

[3] S. Dwivedi et al., accepted at the *OSA Advanced Photonics Congress* 2019, Paper IM4A.3

[4] P. Absil et al., *Proc. of SPIE,* Vol.9367 (2015)