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# Optical Phased Array for 905-nm LIDAR applications integrated on 300mm Si-Photonic Platform

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***Abstract—****In this paper we present the first integration of a 2D Optical Phased Array (OPA) for 905nm LIDAR applications on our 300mm SWIR photonic platform DAPHNE, based on Si & SiN components.*

## I. INTRODUCTION

Today, Silicon photonics technology provides solutions for huge data processing and is taking benefits from industrial manufacturing infrastructure of 300mm CMOS to propose low cost and reliable technologies [1]. But as the data market is booming, the need for sensors in mobile and automotive markets is also in fuller growth. Indeed, the development of 3D scan sensors for short-range and long-range applications may serve consumers market (e.g mobile for more accurate sensors) or automotive market for driving assistance. Optical phased arrays (OPA) based on silicon photonics have become an emerging solution for reliable and low-cost beam steering control for LIDAR application due to the absence of rotating part, and the low unit costs associated with Si-photonics 300mm fabrication technology. Most of the proposed solutions are based on 1550nm scanning wavelength for compatibility with Si-based OPA [2,3] allowing to reuse several building blocks developed for telecom applications to perform coherent detection and Frequency Modulation of Continuous Wave (FMCW) of the laser source. Still, these solutions are under development [4], and ToF detection is still of interest for faster time to market. Indeed, mature technologies such as Si-SPAD (Single Photon Avalanche Diode) are available for receiver operation, providing an operating wavelength within the 900-1000nm range for the emission. Based on this observation, there would be an interest for proving an integrated beam steering device without any moving part operating at 905nm. To cope with this problem, this paper proposes to rely on an industrial Silicon Photonics platform for low-cost processing of SiN-based OPA for 905nm compatibility, allowing both modulation in SiN with local heaters but also co-integration with active Si-devices for in-situ monitoring and other optical functions. While some demonstration of OPA for 905nm LiDAR have been made [5] with 200mm SiN platform, this demonstration is the first done on a 300mm wafer industrial platform with all components previously dedicated to SWIR domain.

## II. 300-MM PHOTONIC PLATFORM ADAPTATION FOR 905-NM OPA INTEGRATION

### *A. Process adaptation*

Our 300mm Photonic DAPHNE platform for OPA integration at 905nm is basically the same as for highly performant datacom devices [1]. It is based on a 310nm thick SOI layer with a 1.5µm BOX, and the process includes active and passive Si-devices, Ge and Si PIN photodiodes, and 2 types of SiN waveguides (600nm & 350nm thicknesses). The platform has been adapted to test new kind of PECVD SiN, and to integrate TiN heaters above the SiN waveguides. The availability of these Si-SiN adiabatic couplers in the original platform allowed the design of new Si based photodetector dedicated to 905 nm (figure.1). These SiN-Si PiN photodiodes are used for inline monitoring of the 905nm light and we show the responsivity of the PiN Si-photodiode at $\lambda$=905nm for different junctions' lengths, for input light coming from the above SiN waveguide.
The only major improvement of the platform was to integrate TiN heaters for thermo-optic control. 50nm TiN with SiN hardmask was patterned above Metal 1 level to keep a 600nm distance with the SiN waveguides. Etching process of via and Metal 2 is optimized to ensure perfect landing on both TiN and Metal 1 copper line.

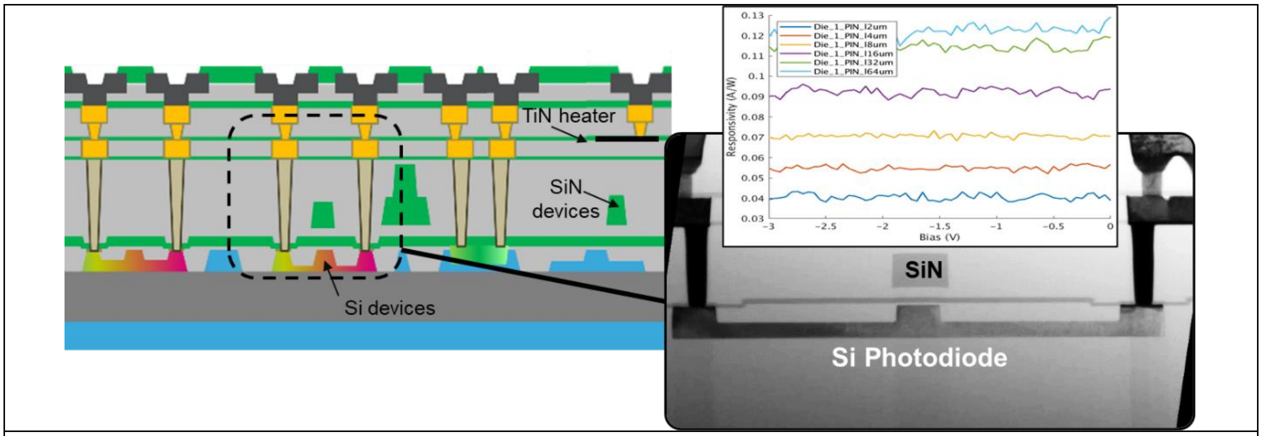


Figure 1: Our 300mm Si-Photonics platform process including Si active & passive devices, Ge & Si Photodiodes, SiN waveguides with dual height, BEOL and optional TiN heaters. The responsivity of the Si-photodiodes is given in function of bias & junction length (@905nm)

### *B. SiN material optimization: impact of Si-rich PECVD SIN on waveguide performances*

The SiN waveguides are patterned from a 600nm-thick PECVD SiN layer, by using two sequences of etching to integrate 600nm SiN & 350nm thick SiN guides. This is possible with an oxide filling and CMP process after the first SiN strip etch, and a second etch to locally perform 350nm thick SiN waveguides. 905nm Single Mode Waveguide are fabricated using this 350nm thick SiN layer. To study the optical and thermal properties of the SiN waveguides we tested different concentration of Si in the PECVD deposition process of our SiN. Optical index varied from 1.87 up to 2.44 for the most Si-rich SiN. For the lowest Si concentration, we measured 0,5dB/cm of propagation loss at 1310nm while the 350nm slab SiN-WG loss was measured between 0,5 and 0,8dB/cm at 905nm. By using Si-rich PECVD SiN, optical index was increased to 2,3 and 2,44. The main advantage was the large increase in thermo-optical coefficient that can rise dN/dT=8E-5/K for the highest Si-concentration compared to dN/dT=2E-5/K for the lowest Si concentration. This could lead to larger thermo-optic efficiency to reduce the power consumption of the TiN heaters. However, we see that at 905nm the optical losses become largely degraded, leading to a compromise between power consumption and the range of the beam steering. We used a Mach-Zender Interferometer (MZI) test structure for optical output power vs electrical power characterization (Heater L = 375µm, R = 4,75kΩ) and the electrical Power for Pi shift corresponding to the different SiN materials was extracted. Values of 95mW/Pi, 40mW/Pi & 27mW/Pi for the 3 different PECVD SiN materials with respective index of 1,88/2,3/2,44 were obtained. Despite the demonstration that higher thermo-optic coefficient increases the heater efficiency, the impact in term of loss degradation due to higher absorption @905nm for Si-rich SiN is high. The OPA demonstration was done consequently with the lowest index SiN.

## III. DEMONSTRATION OF 905NM 1D & 2D SCAN OPA

Our DAPHNE platform was then used to integrate 905nm OPA with 16 channels, in which the phase is individually controlled by TiN heaters (see Figure 2). OPA designs with antennas pitch of 2µm & 1µm have been fabricated. A zoom is proposed on the 16-CH OPA to see the 350nm thick SiN antennas and the pitch d. An input fiber is used to inject light into the OPA while probes are used to control the 16 heaters with a NUCLEO driver. The Calibration was done with a hill climbing algorithm, where the FOM (figure of merit) is computed as an overlap integral between OPA target and OPA output for 1D scan. For each antenna, the FOM for each possible phase value between 0 and 2π is evaluated, and finally we applied to each channel the phase shift that gives the best FOM. As expected, the compromise between FOV and resolution strongly depends on the pitch antenna and must be adapted in function of the targeted application. Figure 2 shows that successful beam steering was achieved at 905nm : +/- 15° scan is registered with the camera, without interferences with secondary orders for the smallest pitch. Theorical FOV is not recorded due to camera FOV limitation for the smallest pitch. This 1D scan demonstrates the successful integration of 905nm OPA on our 300mm DAPHNE platform.

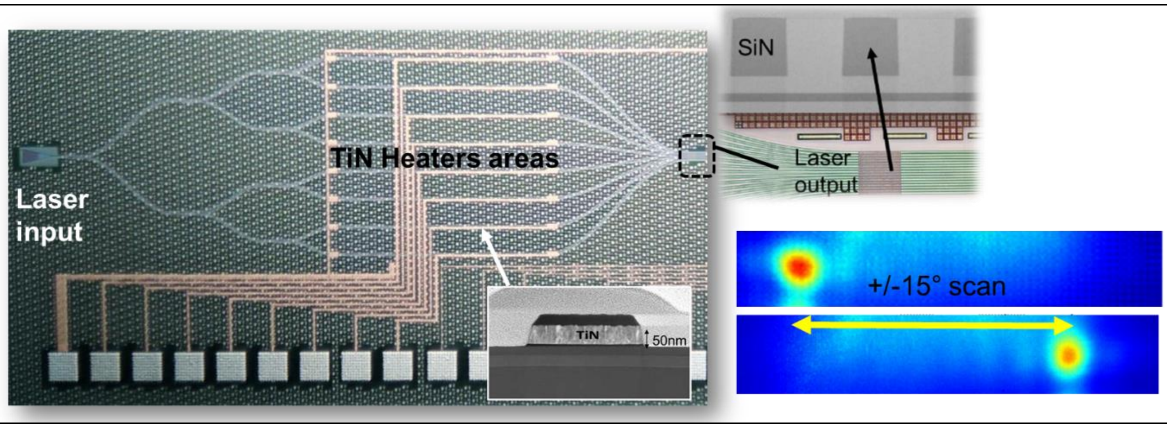


Figure 2: Top-view of 8-channel and 16-channel OPA after final Alu encapsulation and cross section in SiN antennas. OPA where fabricated and characterized on 300mm wafers and tools. Beam scanning obtained at 905nm for 1µm antennas pitch: +/- 15° scan is registered with the camera, without perturbation by secondary orders.

Finally, the figure 3 highlights a 2D scan demonstration thanks to the combination of 4 OPAs. The 4 OPAs are controlled with 4 optical switches for sequential scanning. As each OPA has a different antenna design, output angle along vertical direction is different for each device and complement the X-direction scan obtained with the TiN heaters. This highlights our 2D scan along vertical and horizontal direction.

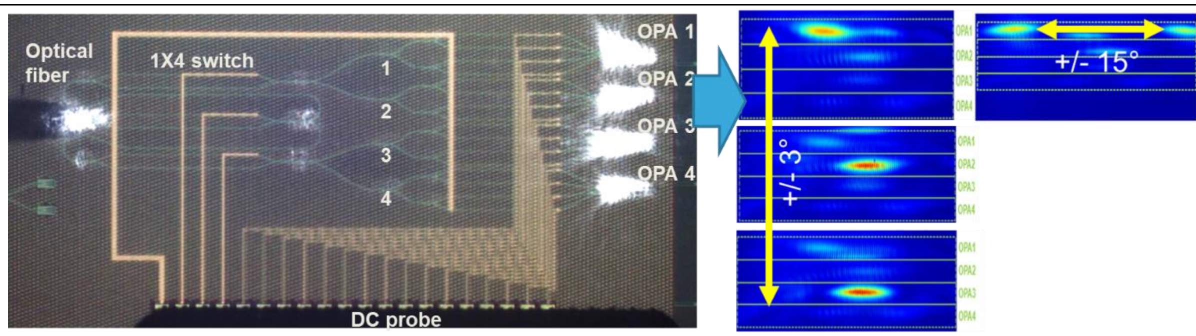


Figure 3: Demonstration device integrating 4 OPAs and 4 optical switches for sequential scanning. As each OPA has a different antenna design, output angle along vertical direction is different for each device and complement the X-direction scan obtained with the TiN heaters. This highlights our 2D scan along vertical and horizontal directions.

## IV. CONCLUSIONS

905nm OPA are an opportunity to propose solid-state beam steering for LIDAR applications with the large advantage of being compatible with highly performant Si-based SPAD detectors for the reception, that are commercially available at low cost. In contrary to more classical 1550nm Si-based technology OPAs, the needed technology platform should integrate several bricks in Si & SiN for this purpose.

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