Silicon Nitride PICs Platform Development from a Foundry Perspective: From Concepts to Real Applications

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ABSTRACT

Silicon Nitride based integrated photonics platforms are going through the stage of fast spread and growth due to many beneficial features such as large transparency window and low propagation losses, presence of Kerr nonlinearity and absence of Two Photon Absorption. To allow integrated photonic devices, the platform capabilities awareness in integrated photonic community and high level of technological maturity are required. At LIGENTEC, we developed the all-nitride-core platform with processes adapted for operation from visible to Mid-IR spectral range and fast fabrication turn-around. Advances and steps towards platform technological maturity from the point of view of a foundry are discussed and demonstrated.

Keywords: Integrated Photonics, Silicon Nitride, High Q Resonators, Low Loss PICs, Hybrid Integration

1. INTRODUCTION

Recent advances in photonic integrated circuits (PICs) technology made the PICs an important part in a variety of application areas from healthcare, bio-sciences and sensors, to LiDARs, high-performance computing and data-/tele- communication. Integration brings opportunities for to-date bulky, complex and expensive optical systems to be implemented in an integrated chip-scale way for increased stability and robust operation, size and power consumption reduction and cost-effective large-scale fabrication of even complex circuits.

While to-date almost any optical element can be done in an integrated way, there is no unique universal material or process to cover all the needs for their simultaneous realisation and to fit for all the application cases, so there are several different platforms employed (SOI, III-V, SiN, etc.), having their own benefits and limitations. Silicon Nitride (SiN) based platforms lately got a growing interest for having large transparency window (visible to MIR) and providing ultra-low losses compared to other PIC platforms. Combined with good thermal stability [1], it makes SiN a beneficial platform for passives. Even though no active components are directly available at the moment, they can be allowed by heterogeneous integration. Absence of Two-Photon Absorption (TPA) [2] allows high power level operations, while presence of rather large Kerr nonlinearity opens new horizons for nonlinear photonics. Silicon Nitride based platform were shown to be a prominent option for sensing devices and bioimaging; supercontinuum [3], optical combs [4] and even photon-pairs generation [5] allowed by (S)FWM in high-Q resonators, which provides a good basis for Quantum PICs and nonlinear photonics applications.

All together, Silicon Nitride based integrated photonics proved itself to be a rapidly growing sector, and manifested a need to prove its capabilities in applications, operation and fabrication.

2. LIGENTEC ADVANCES ON PLATFORM DEVELOPMENT

LIGENTEC is an open access Silicon Nitride foundry. To enforce advancement of integrated photonics and SiN in particular, we developed together with the design house VLC Photonics a Process Design Kit (PDK). The PDK is available in Luceda and Synopsys with basic elements to allow fast and efficient layout design. The company could cover the whole production cycle starting from design assistance to post-fabrication optical characterization. Moreover, Multi-Project Wafer (MPW) runs are offered to allow low-cost prototyping and proof-of-concept demonstrations. Current capabilities of foundries can be found elsewhere [6]-[7], but hereunder the focus is done more on steps being done towards industry-grade integrated devices. As a part of this, we dedicate our efforts to create and enable technical solutions to overcome current challenges and to demonstrate applicability and benificity of the integrated photonics approach.

One recent example for our visible SiN platform AN150 was a study of on-chip large Field-of-View (FOV) Total Internal Reflection Fluorescence (TIRF) microscopy, superresolution and high-throughput imaging. Similarly to sensing technologies, it utilizes the evanescent field from waveguides, and therefore precise film thickness control and high purity of materials are important. This was done as an integral part of our AN150 process optimization, adapted for visible range. Results of this study together with successful demonstration of other functional components allow us to introduce a specially adapted process for applications in a visible range.

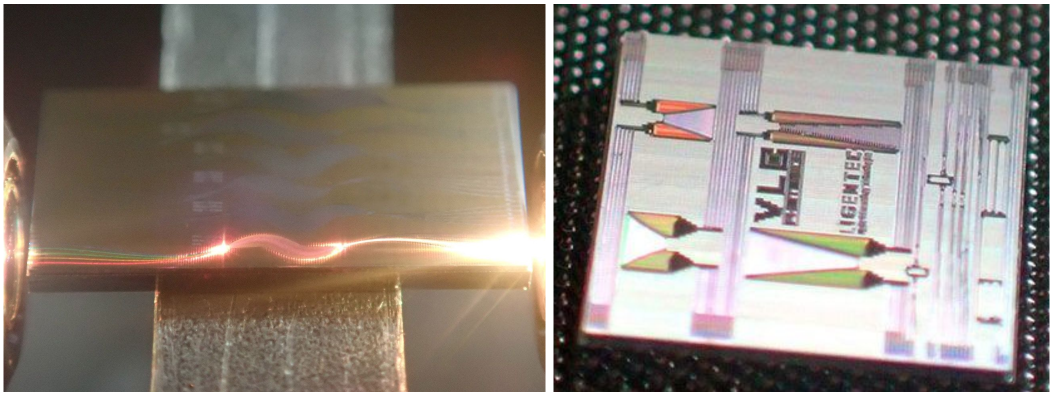

Figure 1. Compact AWGs for visible (left) and Near IR (right) spectral range operation. Chip sizes are 5x10mm (left) and 5x5mm (right). Pictures taken by VLC Photonics.

A lot of interest is gained due to the fact to use the confinement of the optical mode in out thick AN800 platform with SiN thickness of 800nm. This mode-confinement decreases chip size and provides very good propagation losses. Furthermore, AN800 SiN offers nonlinear properties for on-chip combs and supercontinuum generation, which can be utilized for stabilization and calibration purposes as well as for metrology. To enable these technology realizations, dispersion engineering needed for waveguides and high-Q microring resonators is required. Moreover, a wide tunability of devices is often desired, which can be achieved with efficient integrated heating elements. All those features are part of our AN800 process, adapted for thick nitride thickness and optimized NIR-MIR operation. Besides, for this process, efforts were put in development of efficient passives, including fiber couplers, small footprint AWGs, stable and fabrication tolerant MMIs and MZIs and long low-loss delay lines.

To open an access to integrated photonic devices, we work towards PIC packaging standards, as heterogeneous integration can allow benefits of active III-V based elements combined with ultra-low loss SiN passives,while electrical and optical interconnects with the “outside world” are inevitable for any ready-to-use device. SiN is an ideal interposer platform due to its high efficient taper couplers and adjustable spot size converters for chip to chip coupling. To mature the packaging standards and procedures, we establish collaborations with packaging partners, gradually getting closer to possibility of fast and large-scale electro-optical packaging.

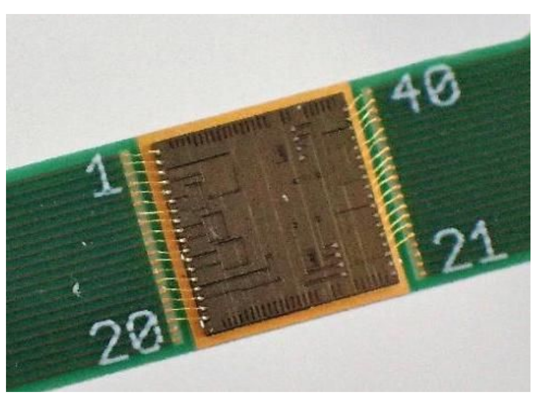

Figure 2. Image of a wire-bonded LIGENTEC photonic chip

To achieve ready-to-use level of PIC applicability, very high degree of control for many parameters is required, and all those collaborative efforts revealed the ones which appeared to be the most crucial in every case: film thicknesses and uniformity (imaging, sensing, dispersion engineering), geometrical dimensions of all the structures (dispersion engineering, reliable passives performance), flatness of bonding sites and local openings (integration and packaging, sensing), alignment precision (multi-layer structures, packaging). To enable integrated photonic devices, the process should be able to reproduce the same layout thousands of times with those parameters within the same specifications. To be able to provide high standards of fabrication, we noticeably advanced the degree of their control and reproducibility up to the level which allow us to claim our platform high technology readiness level not only for streamline planar fabrication, but also for more sophisticated PICs realisation.

To ensure the quality of end-product, evaluation of optical performance (coupling, propagation and bend losses, Q-factors, etc) is done on all the wafers. Dies with reference structures are placed in different areas on a wafer to allow alignment of optical performance with fabrication figures. Semi-automatic measurements of microring resonators with a wavelength sweep are performed routinely, which allows to extract quantitative information on coupling efficiency, achievable Q-factors and deposited materials quality. These measurements provide an additional level of process control on a post-fabrication stage, allowing to provide guarantee not only on dimensions, but on optical performance of delivered products.

3. CONCLUSION

Without any doubt, SiN is one of the PIC technology platforms that significantly evolved in the past few years, and its transparency in the visible and IR wavelength range together with its low losses makes it suitable for a variety of applications. LIGENTEC's advances on platform development and process optimization enable today high standards from low volume prototype fabrication to volume production with performance guarantees.

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