# Silicon nitride passive photonic platform for applications at visible wavelengths: design, fabrication and characterization

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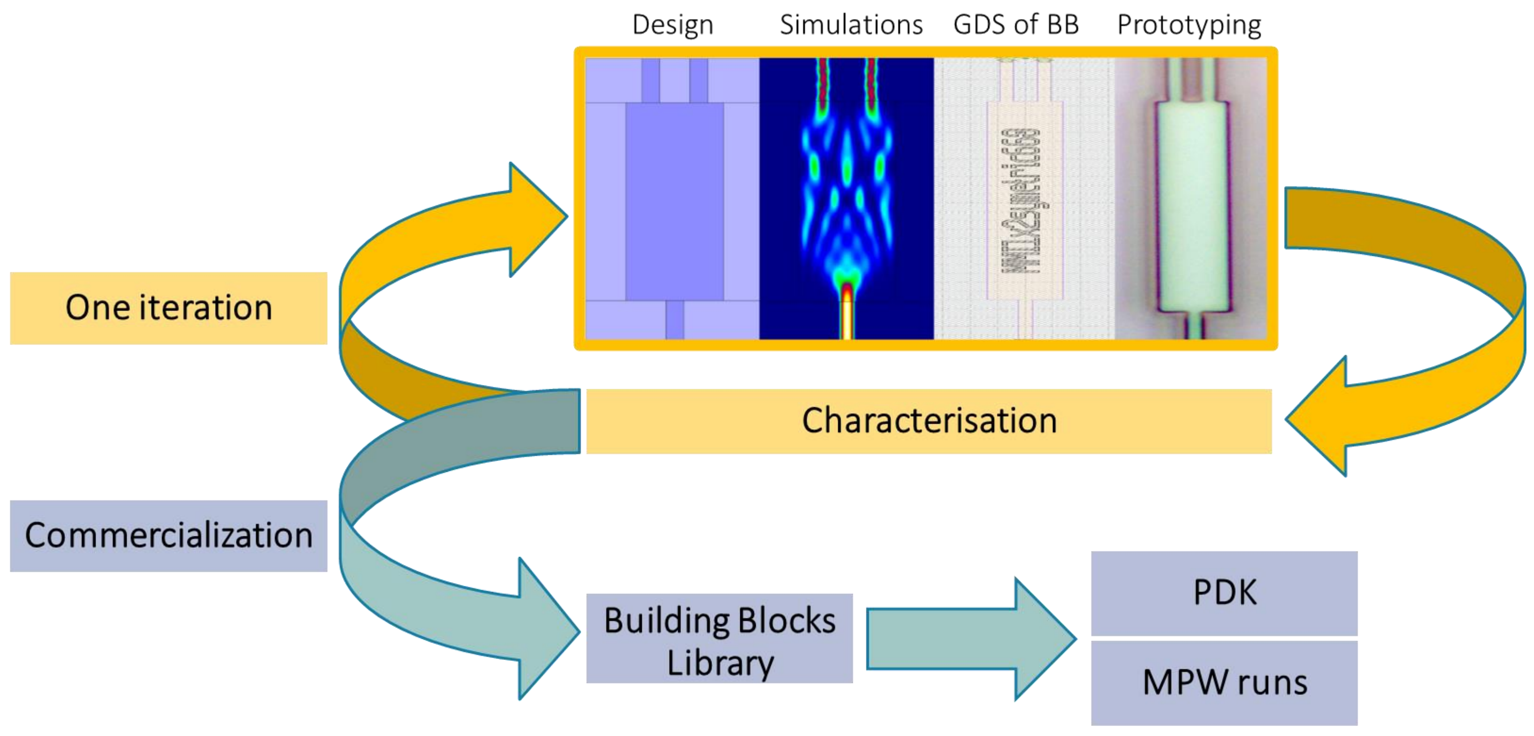
## Introduction

Recent pursuit in replacing electronic devices with photonic integrated circuits in a growing number of applications resulted in silicon nitride ($Si_3N_4$) as a material of choice for development of versatile photonic platform due to:

- Wide transparency window ranging from visible to mid-infrared range
- Low thermo-optic coefficient
- CMOS-compatibility
- Low loss and compactness of the devices

Despite commercial $Si_3N_4$-based platforms available, multiple applications like biophotonics, telecom, datacom and sensing applications and usage in hybrid photonic devices [2] leaves room further improvement and introduction of next platforms to the market.

**In this work we report recent results of development of $Si_3N_4$-based photonic devices as an initial step to establish flexible generic technology photonic platform and to offer multi-project wafer (MPW) production runs. Three sets of test devices have been developed: waveguides (WGs) including tapers and bends, symmetrical multimode interferometer (MMIs) couplers and arrayed waveguide gratings (AWGs)**



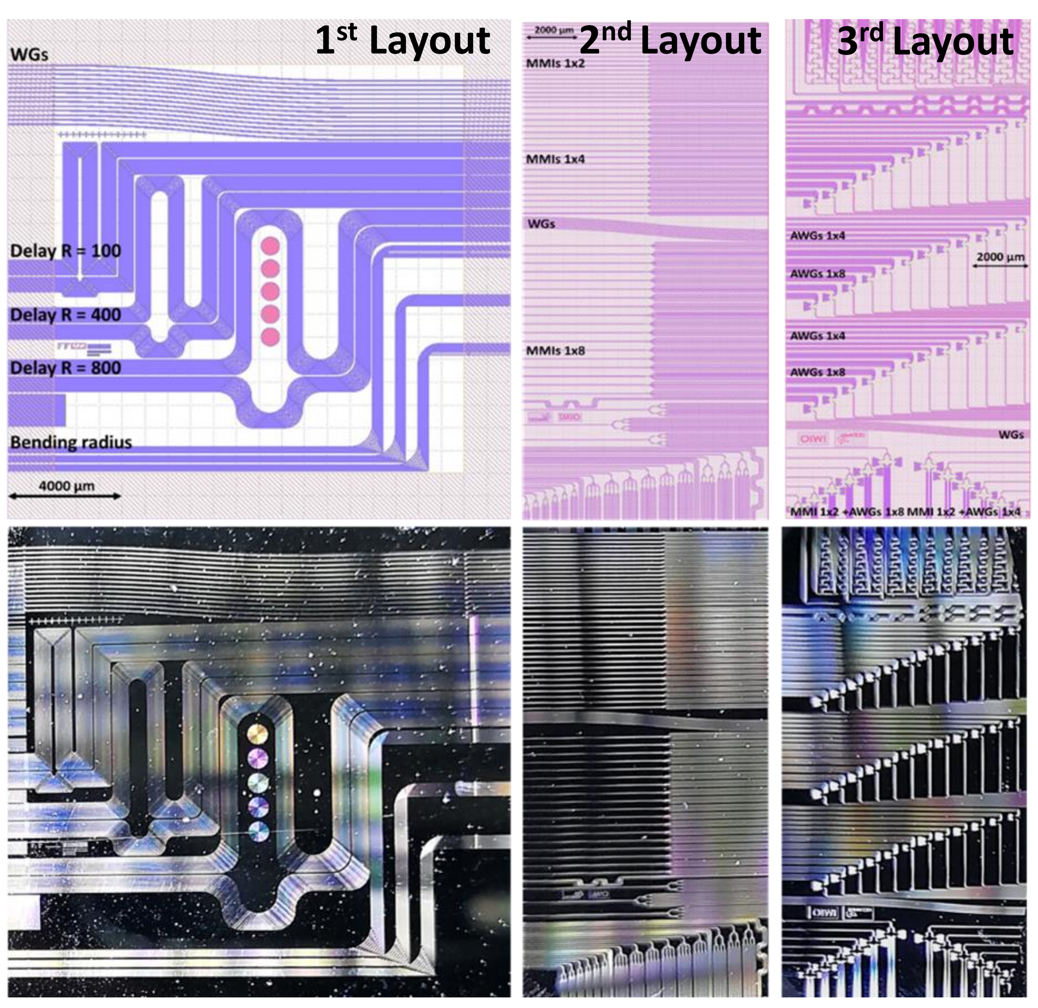

## Simulation and design

Numerical methods implemented in commercial software packages have been utilized for waveguides (WGs) cross-section optimization and later for devices simulations. Film Mode-Matching (FMM) method has been used for investigation of electromagnetic field distribution for modes in WGs and bends. For MMIs and AWGs simulations, a Finite Difference (FD) method has been used.

**1st Layout:**
- WGs of widths from 0.3 µm to 2.9 µm with 0.2 µm step
- Three complex series of delay lines
- waveguides for testing exclusively bending radius influence on losses

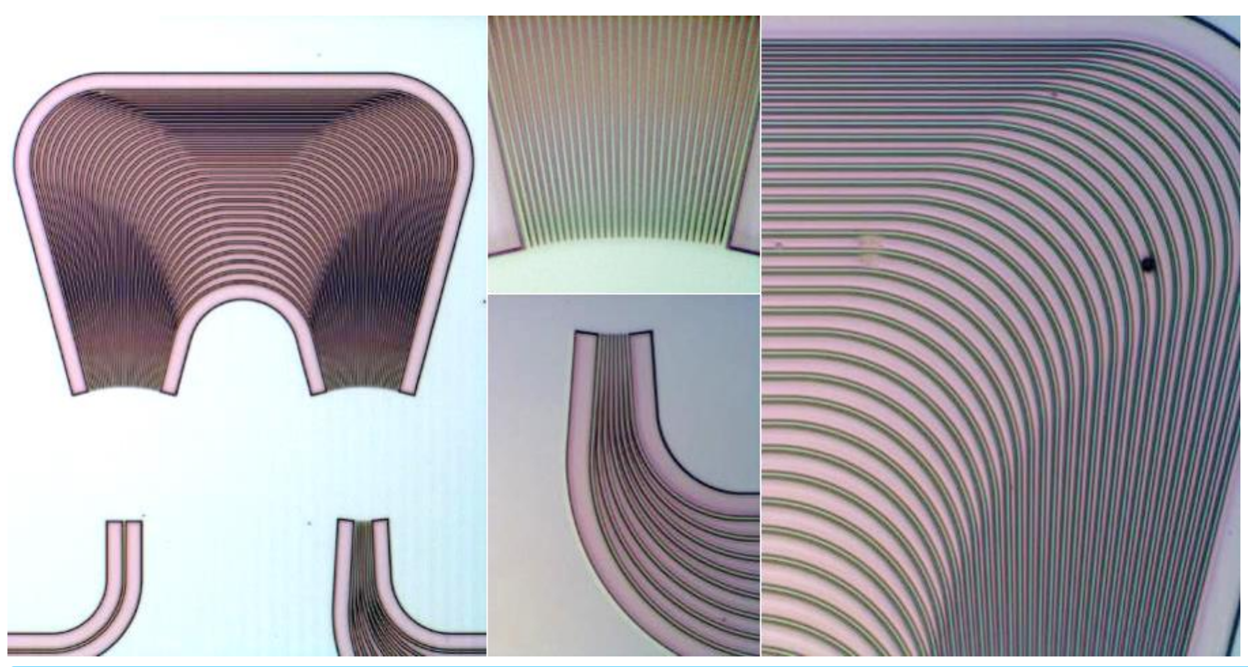
**2nd Layout:**
- MMIs 1x2, 1x4, 1x8 and symmetrical cascades comprising MMIs optimized for 380, 470, 550, 590, 610, 660 nm

**3rd Layout:**
- WGs 90 deg. delay lines
- 3 series of AWGs 1x4 and 1x8 optimized for: 380, 470, 550, 590, 610, 660 nm
- MMIs 1x2 + 2xAWG 1x4 and 1x8 symmetrical cascades optimized for: 380, 470, 550, 590, 610, 660 nm




## Fabrication

- **4-inch silicon wafers (100)**
- **Processing:**
  - Cleaning
  - Oxidation (1200 °C) – 2.3 µm SiO2 layer
  - Low Pressure Chemical Vapor Deposition (LPCVD) – 0.32 µm $Si_3N_4$ layer
  - E-beam lithography with a positive resist - patterning
  - Development and dry reactive ion etching (RIE)
  - Plasma Enhanced Chemical Vapor Deposition (PECVD) – 2.3 µm $SiO_2$ layer



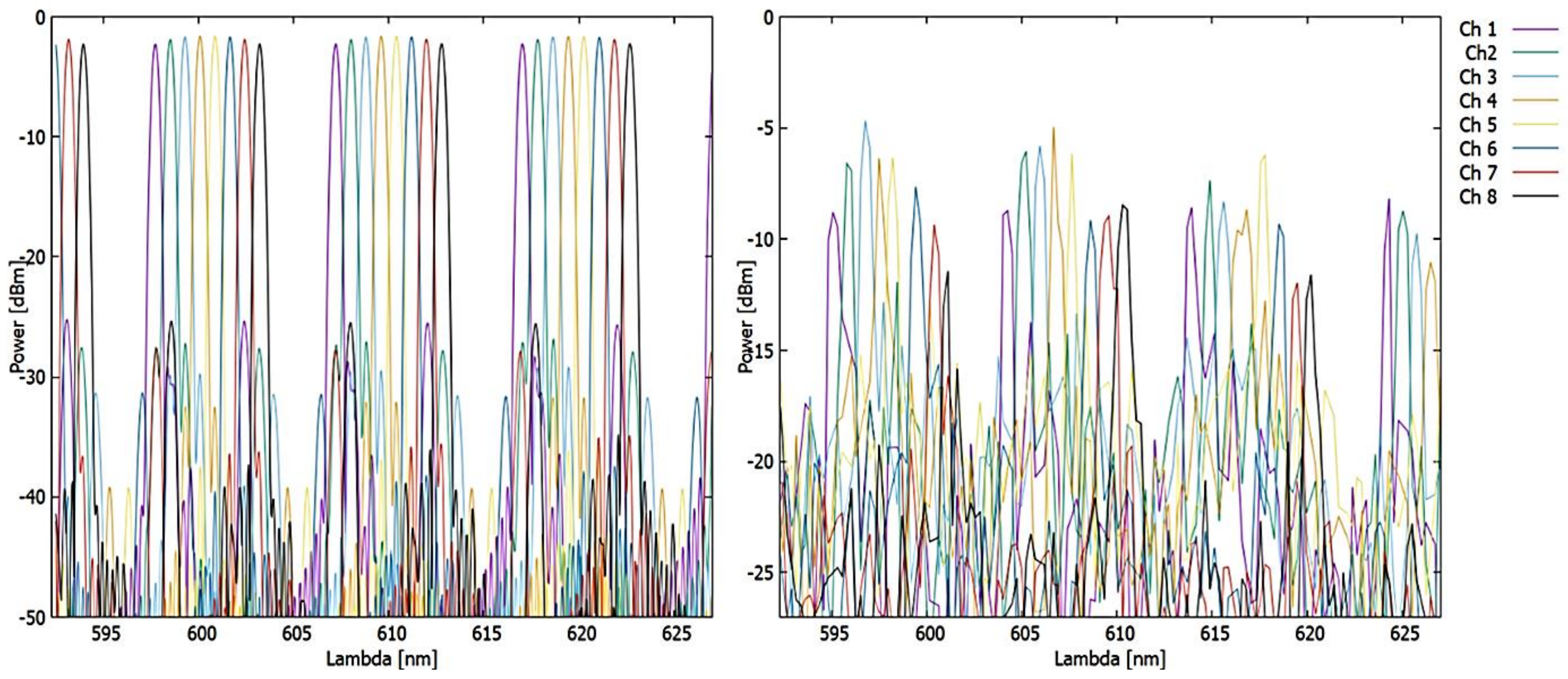
## Characterization

**Characterization setups:**
- 1st: Laser diode – 660 nm and fiber to chip and chip to fiber coupling/decoupling for fixed-wavelength measurements
- 2nd: Ti:Sapphire laser and dye laser for wavelength tuning (570 to 630 nm). Light was free space coupling to chip with 50x objective and decoupling with fiber

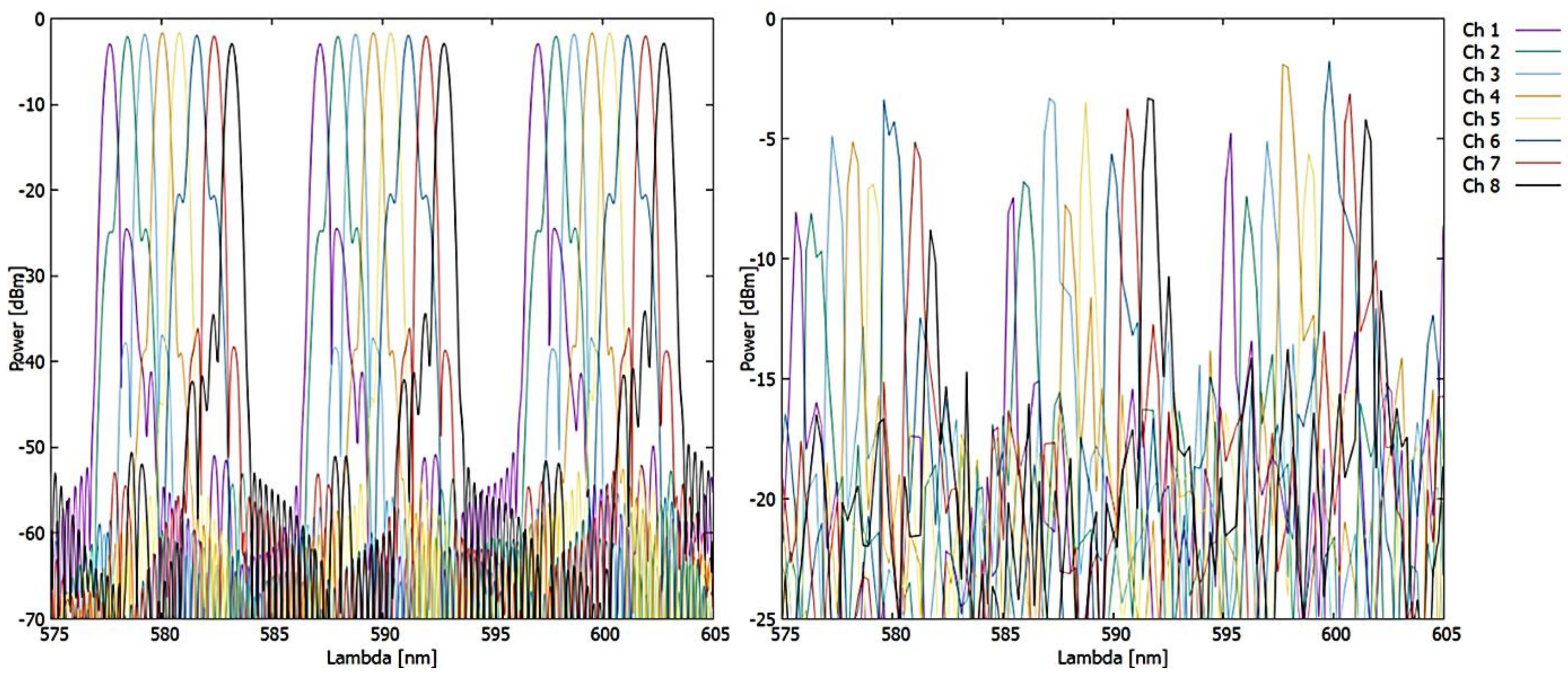
**WGs average loss:**
- Straight WG 1000x320 nm at 660 nm is 1.71 ± 0.50 dB/cm
- 90 deg, 100 µm bend WG 1000x320 nm at 660 nm is 0.21 ± 0.01 dB

**MMIs average loss:**
- 1x2 MMI (λ = 660 nm) 0.49 ± 0.04 dB
- 1x4 MMI (λ = 660 nm): 5.53 ± 0.43 dB
- 1x4 MMI (λ = 610 nm – design, λ = 660 nm – coupled): 9.31 ± 1.55 dB

**AWG 1x8 $\lambda_c$ = 610 nm characterization – design vs measurement:**
- Wavelength range from 590 to 630 nm with resolution of 0.275 nm
- 2.85 nm shift in central wavelength in respect to design parameters
- Channel spacing value of 0.79 nm is consistent with simulations
- FSR derived from measured spectrum equals 9.23 nm vs 9.81 nm simulated value




**AWG 1x8 $\lambda_c$ = 590 nm characterization – design vs measurement:**
- Wavelength range from 575 to 605 nm with resolution of 0.275 nm
- 1.67 nm shift in central wavelength in respect to design parameters
- Channel spacing value of 0.81 nm is consistent with simulations
- FSR derived from measured spectrum equals 10.23 nm vs 9.81 nm simulated value




## Conclusions

- **Working devices of all designed types have been developed within a single production run.**
- **Fast initialization of photonic platform development with current state of technology**
- **Identified sources of inconsistences between simulated and measured characteristics:**
  - Difference between structure temperature chosen for simulations (25°C) and actual temperature of measured structures due to high power coupled into the chip
  - Geometrical offsets between design and fabricated structures
  - Refractive index in simulations not equal to actual one
- **Identified sources of additional losses:**
  - Material chemical and structural nonuniformity
  - Coupling efficiency
  - Edges quality
  - Defects and impurities

## References

*[1] Q. Wilmart et al., "A Versatile Silicon-Silicon Nitride Photonics Platform for Enhanced Functionalities and Applications," Applied Sciences, vol. 9, no. 2, p. 255, Jan. 2019.*
*[2] P. Muñoz et al., "Silicon Nitride Photonic Integration Platforms for Visible, Near-Infrared and Mid-Infrared Applications," Sensors (Basel), vol. 17, no. 9, Sep. 2017.*