Demonstration of hybrid design and simulation of a low-linewidth laser combining InP and SiN platforms

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Abstract
Hybrid PIC design requires co-design in two or more technology platforms in a single design environment. It has been complex to design such hybrid devices, taking into account both foundry compact models and layout constraints at the same time. A specifically complex example of a hybrid design is a single functional component like a laser having its cavity stretching across two distinct integration technologies. In this paper we present a methodology that establishes co-design of layout and simulation across multiple foundries.
We demonstrate the methodology via recreating a previously reported hybridly-integrated laser in InP and SiN PDKs. The laser is simulated using its circuit netlist, which is created directly from the layout netlist. This direct link between mask layout, index- and compact models, and simulation, allows for the analysis of manufacturing tolerances in both foundries on the laser performance, and optimization of the laser design accordingly.

Introduction

Hybrid integration of photonic platforms plays an essential role in various applications to achieve beyond state-of-the-art performance. An example is low-linewidth lasers, which play a key role in answering the demand for higher data transfer rate and coherent sensing in various applications [1-3]. In particular, a combination of indium phosphide (InP) and silicon nitride (SiN) can be used for these devices. Indium phosphide provides the “active” material used for light generation and amplification [4], while the silicon nitride platform provides low-loss wave guiding, hence, enabling long laser cavities, and low-loss tuneable wavelength filtering [5].
Design and simulation of hybrid circuits poses complications; it requires loading of multiple PDK simultaneously, which is likely to cause collisions in variable names, names for layers and cross sections, and mask-layer numbers. Hybrid circuit design with circuit extraction, e.g. for simulation, also requires the creation of a single netlist across the employed technologies. Hence, a good hybrid design environment must resolve all PDK collisions without burdening the designer. Compact models and building blocks for the activated platforms have to be accessible simultaneously. The layout should have a unified visualisation during layout creation and validation, and a single netlist for circuit level design rule checking (DRC) and simulation. Also, mask export to gds must facilitate automatic separation into independent gds files aimed at the individual foundry platforms.

In this paper we demonstrate hybrid circuit design in Nazca Design [6] using the “HybridFab” concept. We demonstrate layout and netlist integration by reproducing, validating and simulating the layout of the hybrid low-linewidth laser from [7].

Hybrid Fab

In a HybridFab we merge multiple technologies (PDKs) in a design environment. As mentioned in the introduction, loading multiple PDKs simultaneously easily leads to data and variable collisions. For variable names this is simply resolved via Python namespaces, providing a unique namespace per PDK. The syntax in Snippet 1 shows the namespaces of “inp” and “sin” PDKs, loaded as Python modules. As a result, the building blocks per technology can be easily addressed, as shown for the mmi2x2 block in the snippet. For layers and cross sections, their IDs are automatically adapted in the HybridFab using a unique internal technology ID per module or PDK. Examples for addressing technology specific layers are also shown in the snippet by using Polygons.

```
# assume PDKs for “inp” and “sin” with both layer “Ridge” and cross section “Waveguide”.

import nazca as nd
import inp
import sin

# Address building blocks technology specific:
mmi1 = inp.mmi2x2()  # an InP MMI
mmi2 = sin.mmi2x2()  # a SiN MMI

# Address technology layers in calls:
# A: layers via prefixing:
polygon1 = nd.Polygon(points=[…], layer=”inp_Ridge”)  # InP Polygon
polygon2 = nd.Polygon(points=[…], layer=”sin_Ridge”)  # SiN Polygon

# B: layers via technology ID:
polygon1 = nd.Polygon(points=[…], layer=”Ridge”, tech=”inp”)  # InP Polygon
polygon2 = nd.Polygon(points=[…], layer=”Ridge”, tech=”sin”)  # SiN Polygon

# C: layers via a global technology state for backward compatibility of code:
# set state ”inp” ...
polygon1 = nd.Polygon(points=[…], layer=”Ridge”)  # InP Polygon
# set state ”sin” ...
polygon2 = nd.Polygon(points=[…], layer=”Ridge”)  # SiN Polygon

# Create an InP to SiN assembly and netlist interface with pins named ‘a0’ and ‘b0’:
with nd.Cell(“inp2sin) as inp2sin:
    # define connector cell
print(inp2sin.pin[‘a0’].xs)  # => xsection = ”inp_Waveguide”
print(inp2sin.pin[‘b0’].xs)  # => xsection = ”sin_Waveguide”
```

Snippet 1: Syntax example of PDK separation at the script level in Nazca.

A HybridFab design is demonstrated with the circuit in Figure 1, recreated from [7]. It consists of an InP amplifier and a SiN reflective wavelength-filter. The InP amplifier consists of a SOA with high-reflectance (HR) coating on the back facet. The SiN filter consists of a directional coupler with a double-ring Vernier filter to create a low-linewidth signal. Export to gds automatically takes care of gds file separation per foundry, as indicated by the “submission” flow in Figure 1, bottom right.

For visualization of the hybrid layout, the “visualization” path as indicated in Figure 1 (top right) applies; the full layout across technology platforms is visible. The mask layers are grouped per technology in the layer list and they are displayed showing their original layer name and number. In the background, the HybridFab concept has mapped the layers to new unique layer numbers and names to avoid collisions.

The netlists of the InP and SiN PICs have to be connected with a dedicated netlist connector block for a complete netlist. This connector block is a (potentially) zero length component and contains a compact model to describe loss and reflections at the interface between the PICs. This block has also been indicated in Snippet 1.

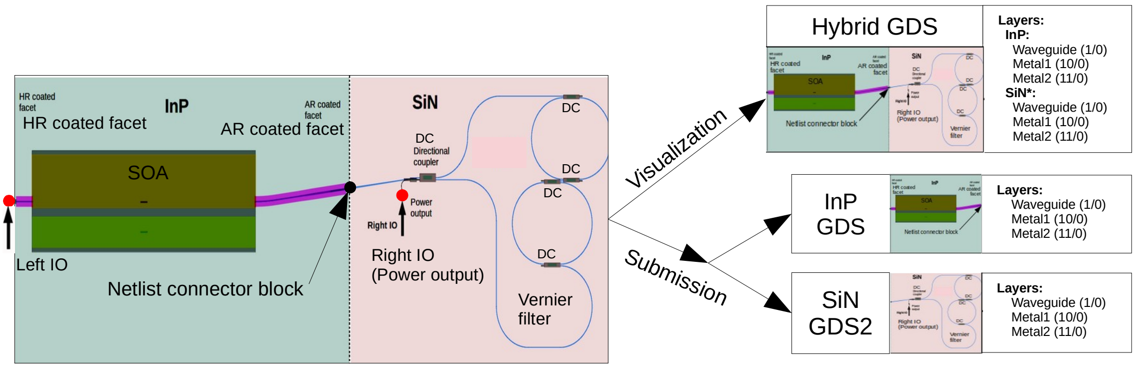

Figure 1: The hybrid design and the flow for visualization and export in Nazca Design. The circuit [7] is composed of an InP gain section with a wavelength-selective mirror having directional couplers (DC) on SiN. The two technologies are connected using a netlist connection block, indicated by the black dot. The red dots in the layout indicate the input and output ports for the PHIsim simulation.
** = layer numbers are mapped to other numbers in the background to avoid collisions.*

When exporting the circuit for manufacturing, the “submission” path applies, as indicated in Figure 1 (bottom right); The layout design splits into multiple gds files based on the technology ID of the mask layers. This allows the designer to submit the respective gds files to the respective foundries, while ensuring perfectly matching interfaces in the full design.

Simulation

Simulations of the circuit from Figure 1 are performed using the recently developed interface [8] between Nazca Design and the PHIsim simulator [9]. The simulation parameters and building block parameters are adopted from [7], where available. Other parameters use the PHIsim defaults.

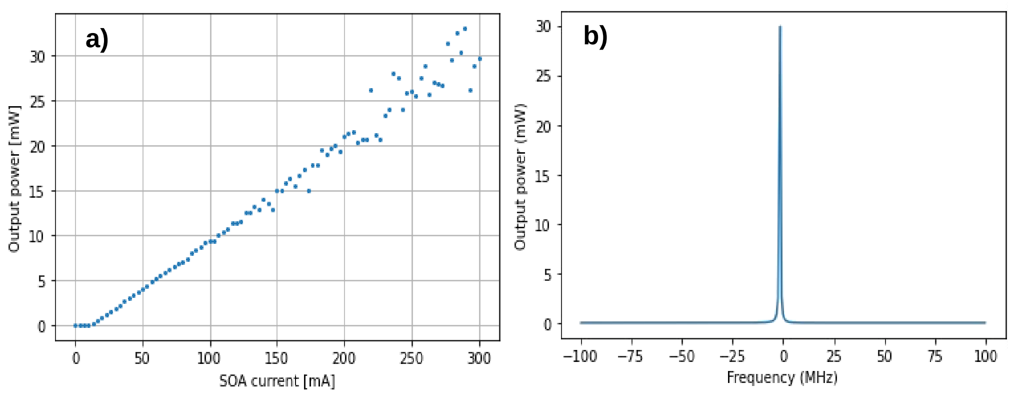

Figure 2: The simulation results of the circuit from Figure 1. a) Output power as a function of the current applied to the SOA, used to determine the threshold current and slope efficiency of the laser. b) Spectral response of the circuit at 300 mA SOA current, used to determine the laser linewidth.

To determine the threshold current and the slope efficiency of the laser, the output power is plotted for increasing SOA current in Figure 2a. The threshold current of the simulated laser is 13 mA and the average slope efficiency is 0.10 mW/mA, compared to 19 mA and 0.13 mW/mA in the experiment. A reasonable agreement, given the fact that not all design parameters from the reference laser are known.

To estimate the simulated linewidth of the laser, we plot the output power in the frequency domain in Figure 2b. The maximum simulation time, which also determines the resolution for the linewidth, is limited by the simulator to prevent memory overflow when loading the results in Python. In this case, the limit for the number of simulation cycles was 1e8. Therefore, the maximum achievable spectral resolution is 634 kHz. With this in mind, we conclude that the linewidth of the simulated laser is at least smaller than 634 kHz. Reproducing the demonstrated linewidth of 2.2 kHz in the paper would need longer simulations and some memory optimizations in the data processing in future work.

Conclusion

This paper has demonstrated hybrid-integrated PIC design in Nazca Design with a single netlist across technology platforms using a “HybridFab” concept. The unified netlist enables simulations of the full circuit and allows more complete design rule checking. Simulation and interface matching of the layout using a unified netlist was more specifically demonstrated with a hybrid InP + SiN laser from literature. This tooling development allows designers of hybrid integrated circuits to more efficiently design and validate their circuits before manufacturing.

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10 PhotonDelta Flagship project: https://www.photondelta.com/news/flagship-project-kick-off/