Unifying PIC laser simulation and mask layout: a new methodology demonstrated on a mode-locked-laser design

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Laser simulation and mask layout for photonic integrated circuits (PICs) typically take place in different design environments. This disconnect impairment can easily lead to laser designs that do not comply with manufacturing constraints, or errors in translating laser parameters from simulation to layout, e.g. optical path lengths. In this paper, we present the integration of two open source software tools for the development of complex laser circuits: layout tool Nazca Design and traveling wave simulation software PHIsim. The foundry compatible Nazca layout tool is used to build the laser circuit, which then one-on-one translates into the laser simulation model using the compact models in the foundry description. This method creates a linear design flow in contrast to commonly used back-and-forward approaches between layout and simulation. Our solution allows designers to use the standard Nazca interface for drawing layout and subsequently simulate the laser circuit straight from the layout netlist, hence, cutting out the need of complex auto-routing and allowing the designer to check the design rules and footprint in this preliminary phase. This not only saves design time but also leads to a better agreement between simulation and layout. The integration is demonstrated with a mode-locked laser PIC.

Introduction

Photonic integrated circuit design flow is currently divided in two different environments: a simulation environment and a layout environment. The typical workflow starts in a simulation interface with a simple circuit schematic and after that the circuit is converted into a layout. The designer carries out the passage from circuit schematic to layout, in most cases, even if a lot of commercial tools for circuit simulation have an export to layout option. The main difference between the automatic export of circuit schematic from the circuit simulation software and the methodology proposed in this paper is the need for the first of complex auto-routing algorithms that often end in wrong designs and unpredictable and/or inconvenient shapes of the connection elements. This is easy to understand, because the circuit schematic does not carry detailed information on the placement and position of the building blocks besides their connectivity. Another underestimated factor in the standard workflow is the layout footprint, because the circuit schematic does not carry information about layout details, although this is often a critical parameter.

Instead, the method that we present here uses the known Nazca interface as a netlist builder for layout and circuit at the same time. The resulting netlist and data models are sent to the PHIsim laser simulator. This interface approach allows for parallel checking for design rules violations and footprint options. It saves time, avoids translation errors between layout and simulation and, therefore, ultimately guarantees a better agreement between simulation and manufactured layout than without this interface.

Nazca Design [1]

Nazca Design is a framework for integrated photonic circuit design written in Python3. The tool is open source and created from the designer's perspective. Nazca Design supports a full hierarchical approach based on creating cell elements (building blocks) and placing them. This opens the possibility for designers to, for example, create reusable modules across different designs. It is important to notice that the essential part of Nazca is a netlist builder based on powerful syntax concepts, which makes it ideal for the representation of both circuits and layout at the same time.

PHIsim circuit simulator [2]

PHIsim is an open source traveling-wave finite-time-difference circuit simulator written in C. It consists of an extended library of building blocks with waveguides, couplers, modulators, amplifiers and saturable absorber. In order to solve the circuit, Phisim splits it into segments of the same length. The propagation equations of lights are solved per each segment and this procedure repeats until the maximum number of simulation cycles is reached. PHIsim implements physical effects that are present also on commercially available software. Unique in PHIsim is the amplifier model that includes two photon effects and the Kerr effect.

There are currently limitations in the physical model of PHIsim worth addressing. Firstly, the model does not include dispersion effects and difference between self and cross-gain saturation. Also, the amplifier block gain is flat, meaning it is the same for all wavelengths. The flat gain can be seen as an inaccurate approximation with respect to the more popular parabolic approximation, although the difference between the two can be partially compensated by the use of additional filters like Mach-Zender or low pass filters. Thirdly, PHIsim requires the manual creation of multiple text files to describe the circuit elements, their connections and the starting conditions for the simulation. This is rather cumbersome and it has been stalling the adoption of PHIsim by a larger community thus far. The interface presented in this work completely reverses the latter limitation.

The interface

The presented PHIsim interface is a Nazca module translating the Nazca netlist into a circuit description readable by PHIsim. This approach also allows for future extensions to other (commercial) software tools for circuit simulation. The phisim module in Nazca describes a number of Python classes that support both running laser simulations, as well as visualizing the results. The simulation is set up in the same script file as the mask layout.

Mode lock laser simulation

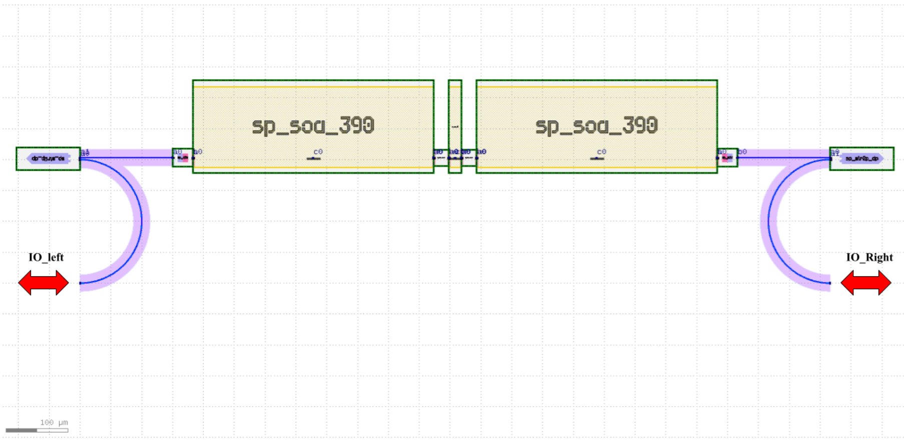

Figure 1: Visualization in KLayout of the mask layout created in Nazca. Input-output ports for the PHIsim simulation are located at the bottom as indicated by the bidirectional red arrows.

To demonstrate the potential of the interface we simulated the mode-locked laser by Gordon et al. [3]. Figure 1 shows the reproduced mask layout in Nazca in our workflow. This already completes the first step towards laser simulation as Nazca automatically created all connectivity information and already performed design rule checking as implemented in the PDK. After creating the layout in Nazca, we need to choose input-output ports of the simulation. Here we add these PHIsim ports to the circuit as indicated in Figure 1. Next we call the interface to create a simulation element. The following code snippet shows all that is needed to run the PHIsim simulation from Nazca and visualize the results:

```
import nazca as nd
import nazca_phisim as nph
import nazca_phisim.BB_phisim as BB  # demo building block library

mysim = nph.Simulation()  # creation of the simulation object

with nd.Cell("mycell") as nazca_cell:
    # Define the Nazca cell

mysim.import_cell(nazca_cell)  # import the cell layout into the simulation
mysim.import_params(BB.Standard_parameters)  # import standard parameters
mysim.create_sim_files()  # creating the txt files for phisim
mysim.run()  # run the simulation and loads the results
mysim.plot_outputs()  # plot the power output per unit time of the laser
mysim.plot_spectra()  # plot the emission spectra
```

Figure 2a shows the PHIsim obtained emission spectra of the mode-locked laser. In the simulated circuit the fundamental mode has a 34.5 GHz spacing and a 68.8 GHz spacing for the colliding pulse mode. When compared with the experimental results in [3] of 34.88GHz and 69.76 GHz, it shows a good agreement, particularly given some limitations of PHIsim as discussed before. The shape of the spectra is obtained by adding a low pass filter in the circuit to improve the approximation with respect to the flat gain. Figure 2b represents the time dependent emission of the laser; it is possible to extract from here a FWHM of 0.67 ps per pulse, against 0.66 ps experimentally [3], again matching very well.

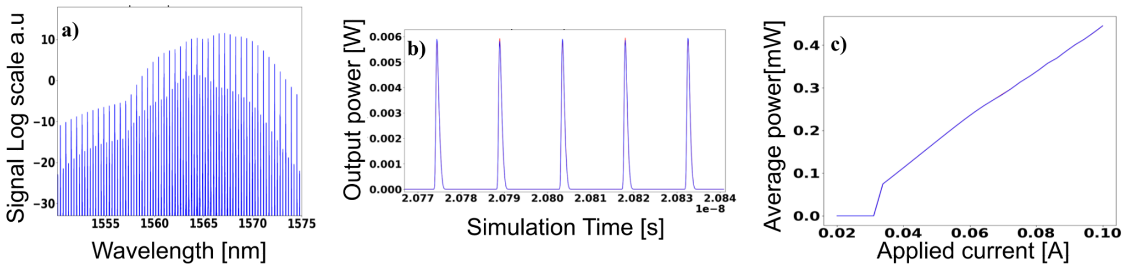

Figure 2 outcome of the simulation, a) logarithmic spectra at 80mA applied current, b) power output vs time at 80mA applied current, and c) LI curve obtained by sweeping the current.

In Figure 2c we report the LI curves of the laser. To obtain this data a sweep parameter was necessary. The interface has an object to make parameter's sweep easy and fast to set up. After setting up the simulation as shown above, a parameter sweep can be run with three additional lines of code to define: the parameter to sweep, the sweeping range and a line to actually run the sweep. The interface then takes care of creating all of the files and organizing them in folders.

Conclusion

In this paper we have presented a new methodology for integrating laser simulation with mask layout design in Nazca Design. The developed interface with PHIsim allows designers to set up and run a simulation directly from the layout design environment of Nazca. This not only saves time in the back and forth between environments, but also provides an additional check to the design before the submission to fabrication. We have simulated with this method a mode-locked laser demonstrating this approach on the simulation of real structures with accurate results. Finally, it is important to notice that all the tools used are open source including the interface.

References

[1] Nazca-design, https://nazca-design.org/
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[3] Carlos Gordón, Robinson Guzmán, Vinicio Corral, Xaveer Leijtens, and Guillermo Carpintero, "On-Chip Colliding Pulse Mode-locked laser diode (OCCP-MLLD) using multimode interference reflectors," Opt. Express 23, 14666-14676 (2015)