Design Challenges in Large-Scale Silicon Photonics
(Invited Paper)

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Abstract—We discuss the challenges in the design flow of complex silicon photonic circuits. The treatment of multi-physics, variability, parasitics at both layout and circuit level is not straightforward. Also, layout automation and verification will need significant developments on existing electronic and photonic design methods.

I. INTRODUCTION

Silicon photonics is gaining rapid adoption by industry and is quickly being developed into a technology for real products. A high refractive index contrast and electronics manufacturing techniques enable new levels of complexity in photonic circuits. However, this introduces significant challenges at the design level. In this paper, we will take a closer look at some of these challenges. These include multi-physics, signal handling, variability, parasitics, and design verification. Apart from these fundamental challenges, there is a need for an effective design flow, with efficient information exchange between the different stages in the design process.

II. INTEGRATED DESIGN FLOW

In a photonics design flow, the designer has to go through several stages. Photonics is still very much rooted in the physical domain, where geometries are optimized for a specific optical function. This is often where the design flow starts TODAY: constructing the atomic building blocks. We can expect that this part of the design flow will shift increasingly to the fab, who will provide validated building blocks in a component library. Still, there will always be a need for design capabilities at the physical level.

The core activity will be in circuit design, where the designer composes circuits from building blocks, and simulates them using abstract behavioral models, rather than direct electromagnetic simulations. Photonic circuit design is still a relatively immature process, and some of the challenges are discussed further.

From the circuit simulation, a physical layout should be derived. This can be done manually, but semi-automatic placement and routing tools should take over for complex circuitry. Finally, the design is verified against the requirements of the fabrication process and at the functional level.

This is not a linear flow. The user will move back and forth in the design flow to optimize physical properties of building blocks or fix design errors in the circuit and layout. An integrated flow where transitions between design steps is largely automated is therefore desirable. This is an area where EDA has paved the way, and where some early photonics solutions are appearing [1], [2], [3].

III. THE CHALLENGES

A. multi-physics

Silicon photonic devices often require direct physical modeling, as many approximations do not hold well in high-contrast structures. In addition, the electrical and thermal properties of silicon often dictate a multi-physics approach. There are several tools that support the joint physical simulator in multiple domains. However, at the circuit level the multi-physical aspect of photonics introduces a significant challenge. Most photonic applications require electrical control so electrical/photonic cosimulation is an essential requirement. Also, thermal sensitivity and the use of active thermal control introduces the thermal domain in the circuit-level simulation. Beyond this, additional physics could be relevant for specific applications: mechanical (MEMS-based devices), fluidic and chemical (sensors) and RF (high-speed communications) are among these.

When looking at circuit simulation methods, we see that many systems fit into an effort-flow formalism, where a given effort (voltage, pressure, force) results in a given flow (current, flow, movement). Such systems can be captured in a SPICE model. However, there is no effort-flow equivalent in photonics, and this requires specific simulation algorithms [4] [5]. Also, for successful circuit simulation, good behavior models are needed that capture the multi-physics behavior with sufficient accuracy to enable reliable circuit simulation.

B. Time scales and signals

Multiple physical domains operate at different time scales. While this can sometimes facilitate modeling (e.g. steady state in one domain) domains cannot always be decoupled. At the circuit simulation level, this could imply that different signals should be handled on different time scales. Photonic signals present their own challenges: Depending on the application, signals contain much more information than electrical signals, and the wavelength and optical signals carry both an amplitude and phase at different wavelengths. Depending on the type of circuit, the effect of the wavelength, the phase, and the wavelength and even the mode for each channel needs to be transmitted. Designing a spectrometer will require full-spectrum signals with a high resolution. This means that at each time step in circuit simulation, hundreds or thousands of numbers have to be transmitted on every connection. It is not yet clear how this can be accomplished in a scalable way, and how this can be integrated with existing electronic circuit simulation tools.
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