A Review of Simulation Needs In Silicon Photonics

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Abstract

Application of silicon photonics is becoming very widespread in high bandwidth optical communication. The electronic-photonic cointegration is a prerequisite for bringing out the best performance out of photonics. This paper gives a view on the different challenges in silicon photonics and the reason why simulation is important for predicting the total behavior of the silicon photonic system. It gives an awareness to the existing tools for simulation and how they should advance to help the electronic-photonic designers.

***Keywords* - Silicon Photonics, Photonics, Simulation Tools, CMOS, Co-integration, EDA**

Silicon photonics is powerful enough to bring about a revolution in the world of photonics. Its compatibility through CMOS fabrication skill offers benefits, like minimum cost, high-volume and dependable manufacturing with a finer accuracy. It has got wide range of applications in advanced instrumentation used in telecommunication and data communication. The entire device can be integrated on the same chip along with the CMOS based electronics. This will reduce packaging density and price. The addition of a photonic layer and interconnects hold the promise of solving speed constraints in future computing and chip platforms as stated by John Bowers [1].

There are many approaches to combine photonics and electronics but they behave as a single complex entity. There is a huge gap in the technology used to design and simulate complex photonic-electronic circuits as suggested by Wim Bogaerts, Martin Fiers, and Pieter, Dumon (Vol.20, No.4, July/August 2014) [2]. This paper intends to offer some view points on the different simulation technologies for silicon photonics and their importance in communication systems. We compare the existing simulation tools used to co-design photonic-electronic circuits and understand the design gap which challenges the co- simulation in silicon photonics.

In section II, we will be giving a small introduction on silicon photonics, devices and components, followed by literature survey and market status. The challenges in silicon photonics will be discussed in section III and the different simulation methodologies will be studied in section IV.

II. Silicon photonics

There is a huge demand for high communication speed and low power consumption electronic systems. Mario Paniccia, Victor Krutal, and Sean Koehl (Feb 2004) observed that with Moore's law pushing processor speeds and increasing volumes of data across the internet, the demand placed on network infrastructure has increased significantly [3]. Silicon photonics technology helps in computing and communication with absolute performance, reduced power, and overall increase in bandwidth. It is the technology in which data is transferred among computer chips by optical waves. It is chip size solution with strong interaction with electrons and photons. The main aim of silicon photonics is to integrate all the optical components onto a single chip. This will reduce the cost and potentially increase the performance of systems for a given application. Richard Soref concluded that "lasers, light emitters, and wave guided components such as ultrafast electro-optic modulators and detectors are the different components in a silicon photonics based system" [4].

Silicon waveguide forms the basic building block of all photonic circuits. Wikipedia explains the fabrication of a silicon photonics structure as silicon etched on the upper layer of silica. This is called as Silicon on Insulator (SOI) [5]. Silicon is virtually transparent to wavelengths greater than 1100 nm(1.1μm). The refractive index of silicon is around 3.5.

Silicon dioxide (SiO_2) shares its chemical composition with glass fiber and has a refractive index which is about 1.5. The difference in the refractive index allows the production of waveguides on the nanometer scale [6]. The variation in refractive index between Si and SiO_2 provides strong vertical confinement of light travelling in the silicon over layer of SOI. The waveguide turns with a radius of only a few micro-meters. This allows combination of many optical building blocks like switches, couplers, modulators, multiplexers etc. on a single chip.

As depicted in Figure 1 (see Appendix A), high volume CMOS foundry manufacturing process has been successfully applied to silicon photonic devices by companies. The companies have been fruitful in fabricating waveguides, light multiplexers and photodetectors using silicon manufacturing process. The basic behavior of the standard components of photonics can be described by the device models. The Electronic Design Automation (EDA) tools are used to define a assembly of interconnected components and to forecast the performance of complete design. James Pond, Chris Cone and Lukas Chrostowski, Jackson Klein, Jonas Flueckiger, Amy Liu. Dylan McGuire, and Xu Wang (2014) developed "a design flow that combines EDA software along with optical simulation software" [7].

Thus, the photonic-electronic co integration is an important aspect to be considered to meet with ever growing bandwidth demands. It is the blend of semiconductor technology with the optical technology which is yet to be establish itself on the CMOS platform. There are many players in the market working towards this co-integration of CMOS and photonics technology by trying to co-design and co-simulate them on a single platform. There are many challenges which needs to be taken care of in the process.

III. Challenges in silicon photonics

Silicon is compatible with the CMOS manufacturing technology. Silicon photonics needs exactly drawn and characterized curved structures due to the wave nature of light. But electronic circuits are characteristically defined in terms of orthogonal shapes i.e., parallelograms. Micheal White (2014) stresses on "the need to precisely deal with curves and the adjustment of IC design tools and foundry processes to photonics" [8].

The silicon photonic interconnects i.e., optical waveguides will perform as anticipated for a given wavelength of light connecting photonic devices only if the curves are very precise. Language and tools are needed to verify that the predefined component waveguides will work equally in each new design setting. Electromagnetic simulations are used for the physical design of elementary building blocks. The simulated behavior should then be used in-circuit simulators.

Electronic circuits are resistant to distortion in the shapes reproduced on the wafer. But photonic circuits are very sensitive to the precise shapes of the devices and waveguides applied in silicon. So, these differences must be lessened or well-thought-out when considering the working of the photonic system.

Many design rule checking (DRC) errors happen when the normal design rules for CMOS processes are applied to a curved photonics design. The layout versus schematic (LVS) tools effectively support the curved structure of silicon photonic devices.

Optimizing photonic devices is a computationally rigorous task. It is hard to extract interactive models for application in circuit simulations, since high contrast refractive index introduces very low lenience to any change in geometry. Therefore, a lot of physical design repetitions of specific building blocks is still involved in photonic circuit design as concluded by Wim Bogaerts (2013) [9].

Silicon photonics technology for circuits and systems requires standardization in the design flow like that which is available for electrical circuit design. The simulated behavior should then be reduced into a condensed model which can be used in a circuit simulator like SPICE. The electronic functions become more integrated as the photonic chips become more complex. This imposes requirements on the design side. Thus, an efficient co-design and co-simulation between the photonic and electronic domain is required. There should be flexibility and portability in the co-simulation of electromagnetic and circuit simulation on the same field irrespective of the constructional and functional differences between them. There are different methodologies which can be used for this purpose.

IV. Simulation methodologies for silicon photonics

The first step in circuit modeling is fixated on guessing the system behavior in the presence of external signals like electrical and optical signals. Once a circuit is designed, the designer uses the schematic to place the components in a physical mask layout. Then the design errors are checked using design rule checking (DRC), followed by layout versus schematic checking(LVS) after which it is tested under different conditions. Then the lithographic simulations are done and the parasites are extracted if any. The results are verified and then fed back into the circuit simulations to see if the system responds as expected. This also includes various parameters like waveguide lengths and component placement, lithography effects, fabrication non-uniformity, temperature as shown in Figure 2 (See Appendix A). In this step, the circuit simulation considers not only the external stimulus but also the fabrication process and environmental variations as observed by Lucas Chrostowskia, Jonas Flueckigera, Charlie Linb, Michael Hochbergb, James Ponde, Jackson Kleine, John Fergusonf, and Chris Conef [10].

The designing of silicon photonic circuits containing different components is done by using various tools. Thus, the simulation emphasis is on the working and overall performance of the complete circuit. So, the simulations in the frequency-domain and time-domain are chosen. Luca Alloatti, Mark Wade, Vladimir Stojanovic, Milos Popovic and Rajeev Jagga Ram developed a Photonic Design Automation (PDA) that allows designers to define optical structures using abstract and technology-independent layers mapped onto DRC-clean mask design levels [11].

The challenges in the simulation of a silicon photonic circuit includes conversion of large geometric parameters taken from EDA tools and the simulation of optoelectronic parameters. For example, different properties like width of waveguide, radius of the curve, waveguide couplers gap distance, electrical contact positions etc. can be easily taken from EDA tools after design and layout. However, photonic circuit simulation necessitates simulation studies of optoelectronic parameters such as group index, dispersion, S-parameters, and information related to dependence of effective index on applied voltage or temperature. These quantities are difficult to be determined from the geometric parameters of the layout. A combination of physics based computer solvers such as Eigen mode solvers, FDTD and electrical device solvers can be used for electronic-photonic co-simulations.

The bar graph shown in Figure 3 (See Appendix A) gives a comparison of strengths and weakness between Beam propagation method (BPM), Eigen mode expansion method (EME) and finite difference time domain methods (FDTD) as compiled by Dominic Gallagher (The Society for Photonics, Vol.22, No.1, February 2008.) [12]. Speed and memory performance are not given scores since these depend too much on the application. Each method has got its own advantages and disadvantages.

System integration is done by CMOS designers to integrate photonic simulation engines into electrical EDA tools as shown in Figure 4 (See Appendix A). The optical-electronic co-integration is essential to convert the optical circuits into the interactive models which can be inserted into the electrical EDA simulation flow as suggested by Bo Wang, Ian O Connor, Emmanuel Drouard, Lioua Labark

(2010, Springer, Chapter 6, Page 91-104) [13].

Table 1 (See Appendix B) gives the different electronic and photonic simulation tools which are co-integrated for different applications. Typically, these tools and amalgamations support simulation of any complex photonics structure/design and system. Cheryl Sorace-Agaskar, Jonathan Leu, Micheal Watts, and Vladimir Stojanovic (Vol.23, No.21, 7 Oct 2015) developed a Cadence toolkit, written in VerilogA which opens the likelihood for system designers to build and simulate complex mixed electronic-photonic circuits like modulators and ring resonators [14]. Arthur Lowery, Olaf Lenzmann, Igor Koltchanov, Rudi Moosburger, Ronald Freund, Andre' Richter, Stefan Georgi, Dirk Breuer, and Harald Hamster (Vol. 6, No.2, March/April 2000) developed a flexible framework for photonic devices, systems and networks simulation, together with a wide range of numerical modules representing photonic devices and subsystems [15]. "This allows modeling operations/functionalities like sample mode for transmitter (laser) design, parameterized sample (PS) for deviation estimation from true periodicity estimation in long haul RZ systems, combined PS and noise bins (NB)'s for iterative signal-to-noise optimization in an amplified WDM system etc." as concluded by Arthur Lowery et al.

Thus, the modeling and simulation of photonic devices and systems are becoming more substantial. Vittorio M. N. Passaro and Francesco De Leonardis observed that many modeling techniques for photonics is not yet well consistent and many features of simulation tasks are still open such as parametric effects on active and passive blocks in communication system [16]. Jason Orcutt and Rajeev Ram (IEEE Photonics Technology letters, Vol.22., No.8, April 15,2010) designed a methodology to lay out photonic devices within standard electronic CMOS foundry which allowed the production of designs in three foundry scaled-CMOS procedures from two semiconductor manufacturers [17].

The electronic circuits depend extensively on Kirchoff's theorems and photonic circuits on electromagnetic solvers. Depending on the applications for a system, required methodology must be adopted. The designer should be able to optimize the co-design and co-simulation in the same environment.

V. Summary

Co-integration of electronics and photonics is needed to get the best result from photonics. But this co-integration results into many problems in the co-design and co-simulation of electronic and photonic circuits which are complex, there is intolerance to changes in the variables, and the authentication of the algorithms that can handle photonic circuits.

The photonics design must be brought into the electronic design flow allowing the complete properties of the photonics to be accepted by the EDA. Therefore, modified solutions for photonics have to be developed and it must be integrated into the existing workflow so that the differences between photonics and electronics can be sorted out.

Therefore, to co-design and co-simulate complex photonic-electronic circuits we need to understand their working mechanism at the di-electric and metallic interface. The optical and electronic interfacing is a crucial deciding factor and vital challenge in communication systems using silicon photonics technology at high frequencies. This requires different simulation tools to be coupled or integrated with each other in real time systems to bring out the best possible solution for efficient interfacing to ensure minimum losses during transmission and reception.

References

1. John Bowers, Silicon Photonics, UCSB, Optoelectronics Research. [Online] Available: http://optoelectronics.ece.ucsb.edu/silicon-photonics.
2. Wim Bogaerts, Martin Fiers, Pieter, Dumon (2014). Design Challenges in Silicon Photonics. IEEE Journal of Selected Topics in Quantum Electronics, Vol.20, No.4, July/August 2014, doi:10.1109/JSTQE.2013.2295882.
3. Mario Paniccia, Victor Krutal, Sean Koehl

(Feb 2004). Introducing Intel's Advances in Silicon Photonics.

4. Richard Soref, Silicon photonics technology: past, present future, Air Force Research Laboratory, Sensors Directorate AFRL/SNHC Hanscom AFB MA01731, Proc. SPIE5730, Optoelectronic Integration on Silicon II,19(March 14,2005): doi:10.1117/12.585284; http;//dx.doi.org/10.1117/12.585284.
5. Silicon Photonics- Wikipedia, the free encyclopedia [Online]. Available: https://en.wikipedia.org/wiki/Silicon photonics.
6. Andrew P Knights, J. K. Doylend, Silicon Photonics: Recent Advances in Device Development, doi:10.1117/3. 793309.ch30., Advances in Information Optics and Photonics, eBooks, SPIE digital library
7. James Pond, Chris Cone, Lukas Chrostowski, Jackson Klein, Jonas Flueckiger, Amy Liu. Dylan McGuire, Xu Wang (2014). A complete design flow for Silicon Photonics, Proc. SPIE9133, Silicon Photonics and Photonic Integrated circuits IV, 913310(May1, 2014); doi:10.11117/12.2052050.
8. Micheal White, Electronic Design. [Online]. Available: http://www.electronicdesign.com/SiliconPhotonics bring new capabilities to IC design, March 17,2014.
9. Wim Bogaerts (2013). Design challenges in Large-Scale Silicon Photonics, Photonics Research Group, Ghent University- Imec, Department of Information Technology, Ghent, Belgium, Invited Paper NUSOD 2013, doi:10.1109/NUSOD.2013.6633125, IEEE Xplore: 17 October 2013
10. Lucas Chrostowskia, Jonas Flueckigera, Charlie Lin, Michael Hochbergb, James Pond, Jackson Klein, John Ferguson, Chris Cone. "Design Methodologies for Silicon Photonic Integrated Circuits." Proc. SPIE 8989, smart Photonic and Optoelectronic Integrated Circuits XVI, 89890G, (March 8, 2014): doi:10.1117/12.2047359;

    http://dx.doi.org/10.1117/12.2047359.
11. Luca Alloatti, Mark Wade, Vladimir Stojanovic, Milos Popovic, Rajeev Jagga Ram. A Photonics design tool for advanced CMOS nodes.,IET Optoelectronics(2015),9(4):163,

    http://dx.doi.org/10.1049/iet-opt.2015.0003, IEEE Xplore Digital Library.
12. Dominic Gallagher (February 2008). Photonic CAD Matures, IEEE LEOS, The Society for Photonics, Vol.22, No.1.
13. Bo Wang, Ian O Connor, Emmanuel Drouard, Lioua Labark. Bottom-up verification for CMOS photonic linear heterogeneous system, System specifications and Design Languages-Selected contributions from SDL 2010, Springer, Chapter 6, Page 91-104, Volume 106 of the series Lecture notes in electrical Engineering, 08 November 2011.
14. Cheryl Sorace-Agaskar, Jonathan Leu, Micheal Watts, Vladimir Stojanovic (2015). Electro-optical co-simulation for integrated CMOS photonic circuits with VerilogA. Optical Society of America, Vol.23, Issue 21, pp.27180-27203, 7 Oct 2015, https://doi.org/10.1364/OE.23.027180
15. Arthur Lowery, Olaf Lenzmann, Igor Koltchanov, Rudi Moosburger, Ronald Freund, Andre' Richter, Stefan Georgi, Dirk Breuer, and Harald Hamster (2000). Multiple Signal Representation Simulation of Phototonic Devices. Systems, and Networks, IEEE Journal of selected topics in quantum electronics, Vol. 6, No.2, March/April 2000, doi:10.1109/2944.847764.
16. Vittorio M. N. Passaro, Francesco De Leonardis, Photonics Research Group, Italy, Recent Advances in Modeling and Simulation of Silicon Photonic Devices.
17. Jason S. Orcutt, Rajeev J. Ram (2010). Photonic Device Layout with the foundry CMOS Design Environment, IEEE Photonics Technology letters, Vol.22., No.8, April 15,2010.

Appendix A

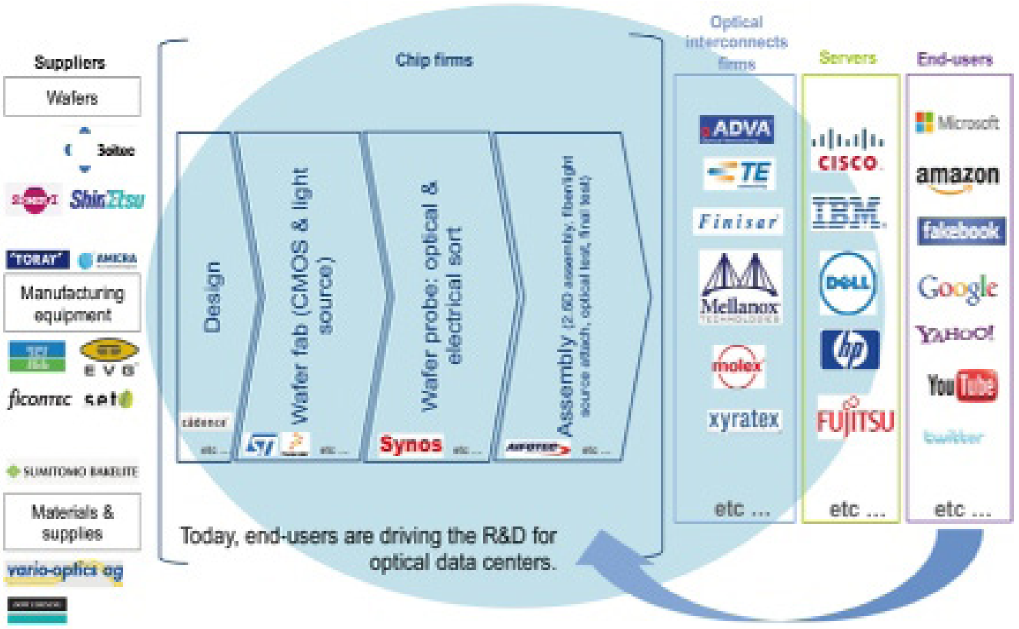


Figure 1 :
Silicon Photonics Supply Chain, (Source: Silicon Photonics 2014 report, Yole development, June 2014)

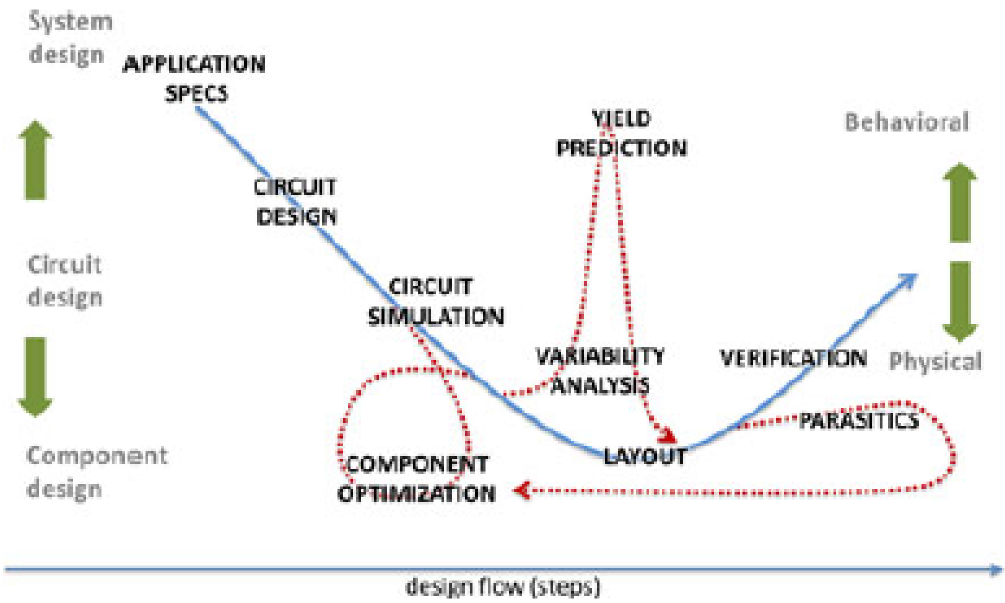


Figure 2 :
Electronic Photonic Design Flow
(Vittorio M. N. Passaro, Francesco De Leonardis, Photonics Research Group, Italy) [16]

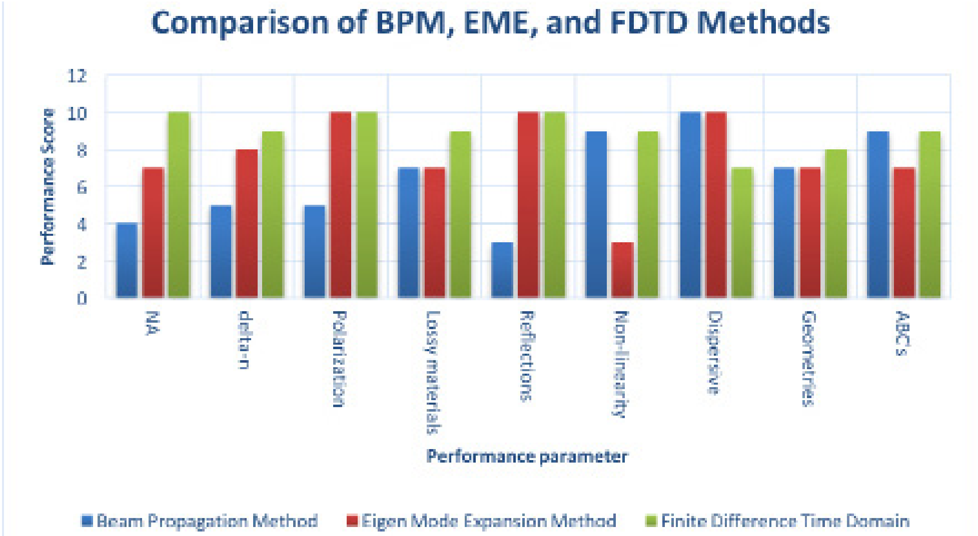
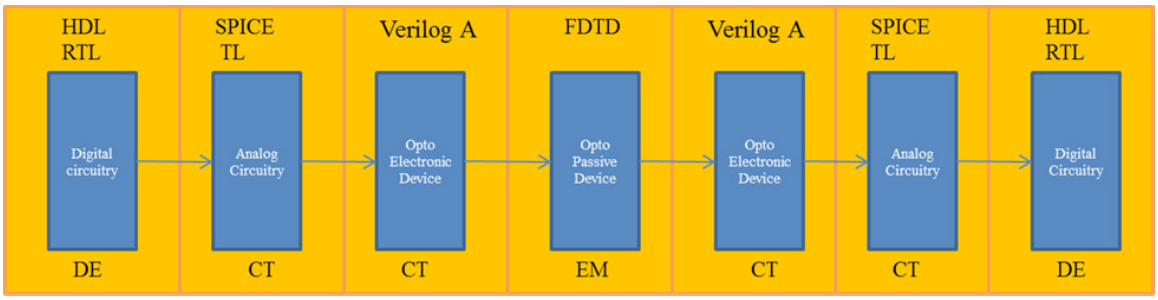


Figure 3 :

Comparison between BPM, EME and FDTD methods



Simulation flow for CMOS Photonics Circuit

Figure 4 :

Simulation tools for CMOS Photonics Circuit [12]

Appendix B

Table I : Electronic photonic Co-simulation tools

Electronic		**Photonic**	
Simulation Tools	**Vendors**	**Photonic Simulation Tools**	**Vendors**
Verilog	Cadence	BPM	RSoft
System C	Mentor	EME	Fullwave
VHDL	Synopsis	FDTD	Pheonix Opto Designer
AMS	Agilent	CMT	Lumerical
		TMM	IMECCAMER
		FV-FEM	PICAZZO IPKISS COMSOL MIT MEEP FIMMPROP

|| ज्ञानमय || March 2017 - May 2017 ISSN No. 2395-7484