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Design of Si-Photonic structures and evaluation of their radiation hardness dependence on design parameters

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A silicon photonic chip for radiation resistance evaluations has been designed and is currently being fabricated in an ePIXfab multi-project wafer run at imec. The chip contains custom-designed Mach-Zehnder modulators, pre-designed "building-block"modulators and photodiodes as well as various passive test structures. The simulation of the custom Mach-Zehnder modulators and the design flow of the chip is presented. We also plan to report on first measurement results of the modulators'radiation hardness as a function of total ionizing dose.

Summary

When the LHC will be upgraded to the high-luminosity LHC in the early 2020's or when new experiments will be built later, new optical components will be installed in the particle detectors. Having the possibility to integrate these optical components with their driving electronics, and possibly also silicon particle sensors, would allow new design paths for LHC's optical readout system. Particularly, integration could entail higher bandwidth, increased functionality and density, lower manufacturing cost and less power consuming optical components. Currently, the only material system that would allow all these advantages to be combined together is silicon. First assessments of the radiation hardness of silicon photonic (SiPh) technology have shown that the performance of standard Mach-Zehnder modulator (MZM) transmitters degrades with increasing neutron fluence and total ionizing dose. A more thorough evaluation of radiation hardness as a function of chip design parameters is required to understand how both interact with each other. Specifically, it is of interest to check if high bandwidth SiPh components with a radiation resistance sufficient for HL-LHC applications can be designed. Devising and fabricating custom SiPh chips with varying design parameters and test structures is the most efficient way to get additional results in this regard.

Access to foundries for processing custom SiPh designs has become considerably simpler with the emergence of multi-project wafer (MPW) runs for silicon photonics. As in electronics, the space of a wafer and its processing costs are shared among multiple customers. This makes SiPh prototyping much more affordable. A custom SiPh chip with several different test structures has been designed and is presently being fabricated at imec within the ePIXfab MPW framework. Since MZMs are among the most promising SiPh-based transmitter devices for high energy physics applications, particular focus has been placed on varying design parameters of MZMs that could influence their radiation hardness.

Before the mask file could be created, simulations were performed to find the optimal optical modulation performance for each parameter set of interest. The electron and hole density in the silicon waveguide as a function of applied voltage is the most important electrical property of SiPh MZMs that needs to be simulated. Synopsys Sentaurus was used to solve the Poisson and current continuity equations and extract the required carrier densities for each potential design. By using the Soref-Benett formula, it is possible to convert a carrier density change into a change of the refractive index in silicon. The resulting refractive indices were imported into the PhoeniX FieldDesigner mode solver to calculate the phase modulation efficiency in the silicon waveguide. Once the best parameter sets were found, the design was implemented into the mask file. The final mask comprises custom MZMs with varying phase shifter lengths, phase shifter shapes as well as doping concentrations and widths. Building block MZMs designed by imec for reference purposes, building block photo diodes, couplers and various passive test structures are also contained in the layout. The additional test structures will allow us to analyze optical losses in dependence of radiation and isolate potential failure causes from an entire MZM.

We present the simulation and design flow of this custom SiPh chip designed for radiation hardness evaluations. We also plan to include initial measurement results of the optical phase modulation efficiencies and current-voltage characteristics as a function of total ionizing dose for MZMs with different design parameters.

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