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Silicon Photonics Circuits for the optical readout of CERN detectors

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The increasing luminosity in CERN experiments enabled by future upgrades demands optical links with enhanced bandwidth and radiation tolerance. Silicon Photonics (SiPh) emerges as the optoelectronic technology meeting these requirements and is being considered for the next generation of optical readout systems of CERN detectors. We present the progress on Silicon Photonics for High Energy Physics (HEP) made in the CERN EP R&D WP6 project. We show the measurement results of the photonics circuits integrated into two test chips designed at CERN, along with the progress on the system aspects of the SiPh radiation-tolerant optical links.

Summary (500 words)

Particle collisions in the CERN Experiments generate a very large number of events, first detected by particle sensors, and then transmitted to a data collection point via optical fibers. Each CERN Experiment is equipped with tens of thousands of optical fibers resulting in an aggregate bandwidth of several tens of Tb/s. Upcoming upgrades of the CERN Experiments and accelerators necessitate optical readout systems with enhanced bandwidth, increased radiation tolerance, low power consumption, and reduced mass.

Silicon Photonics (SiPh) has been identified as the technology of future radiation-tolerant optical transceivers. SiPh gained maturity in the last decade, driven by the market for data centres and high-performance computing for AI applications. This technology uses standard CMOS fabrication processes to integrate optical transceivers into Photonic Integrated Circuits (PICs).

We present the measurement results from two custom PICs designed at CERN and manufactured by imec as part of multi-project wafer (MPW) runs: the SystemPIC and the PackagingPIC.

The SystemPIC incorporates various building blocks for radiation-tolerant optical transceivers, including optical modulators, photodetectors, optical waveguides, fiber couplers, and circuits for on chip polarization control. The design choices aiming to optimize bandwidth, modulation efficiency, and radiation tolerance of ring modulators were based on the knowledge acquired from testing previous custom PIC designs. The SystemPIC operates in the O-band wavelength region (1310 nm), aligning with the standards for commercial off-the-shelf (COTS) components that will be used for the off-detector portion of future links. The COTS required for each link are a 4-channel Coarse Wavelength Division Multiplexing (CWDM4) back-end transceiver and an External Laser Source (ELS) serving as an "optical power supply"for modulators in the front-end PIC. A novelty is the arrival in the market of ELSs for co-packaged optics (CPO). ELSs utilize arrays of O-band Continuous Wave Distributed Feedback (DFB) lasers packaged into a pluggable QSFP module. We present measurements from ELS Beta units coupled to the CWDM4 transmitter circuit integrated into the SystemPIC and based on ring modulators.

Within the EP R&D WP6 project, we developed a Demonstrator ASIC for Radiation-Tolerant Transmitter in 28nm (DART28) that among other functionalities presents a 4-channel 25 Gb/s ring modulator driver output. We successfully demonstrated the on-board integration of the DART28 ASIC and the ring modulators on the SystemPIC using short wire bonds (~400 µm) for the high-speed connections.

Mastering the packaging of PICs with the front-end particle sensors is crucial for SiPh successful adoption in CERN detector optical readout systems. Standardization around fiber optic connection to PICs is still in its infancy. To advance on this aspect, CERN strategically invested in a fiber attachment machine for PICs, scheduled for commissioning in May 2024. To support this activity, the PackagingPIC was designed and fabricated using the imec Passive+ SiPh platform. This PIC integrates several test circuits for edge coupling of optical fibers that offer low coupling loss across a wide wavelength range: IL < 2 dB in 100 nm span. Initial results of edge coupling of the SystemPIC and the Packaging PIC using the fiber attachment machine will be presented.

Authors: SCARCELLA, Carmelo (CERN); ALFIERO, Daniele (Politecnico di Torino (IT)); CRISTIANO, Antonio; DETRAZ, Stephane (CERN); MUTHUGANESAN, Hemalatha; OLANTERA, Lauri (CERN); QUINTANA, Inmaculada; SIGAUD, Christophe (CERN); SOOS, Csaba (CERN); TROSKA, Jan (CERN)

Presenter: SCARCELLA, Carmelo (CERN)

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