

Integrated optical transceivers: architectures, key technologies, and applications

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Driven by the rapid proliferation of Artificial Intelligence (AI) and High-Performance Computing (HPC), modern computing infrastructure faces dual challenges in both computational power and interconnect scalability. In the context of explosive growth in data center traffic, legacy copper-based electrical interconnects are

approaching their physical limits due to severe signal loss and signal integrity degradation. Exacerbated by high-frequency attenuation and crosstalk, electrical links are often compelled to trade complex equalization schemes and excessive power consumption for sufficient link margin. Consequently, the "bandwidth wall" and "power wall" have increasingly become critical bottlenecks limiting overall system performance.

Optical interconnects, leveraging intrinsic advantages such as high bandwidth, low loss, and immunity to electromagnetic interference (EMI), are thus regarded as a promising solution to these barriers. Furthermore, the significance of integrated optical transceivers extends beyond merely increasing optical link data rates. It fundamentally reshapes the electro-optical interface through a holistic co-design methodology involving the device, circuit, packaging, and architecture. By aligning performance, energy efficiency, and manufacturability within a unified engineering framework, this approach establishes a scalable pathway for next-generation high-bandwidth-density interconnects.

The research group of Prof. Xingjun Wang from the School of Electronics at Peking University published an invited review article titled "Integrated Optical Transceivers: Architectures, Key Technologies, and Applications" in Opto-Electronic Technology (2026, Issue 2).

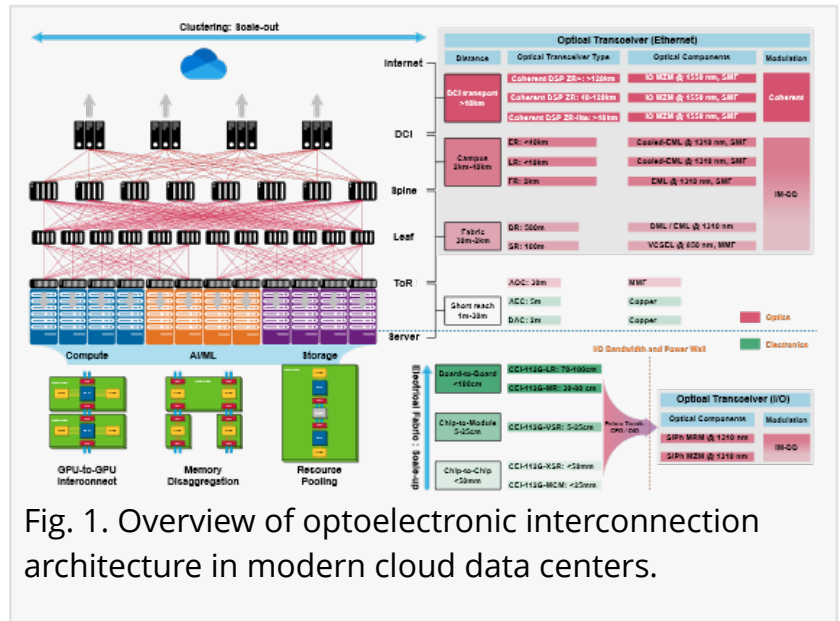


Fig. 1. Overview of optoelectronic interconnection architecture in modern cloud data centers.

The article notes that traditional pluggable optical modules are approaching their scalability limits in terms of footprint, power, bandwidth density, and cost. Addressing this bottleneck, Co-Packaged Optics (CPO) has emerged as a transformative solution. By tightly integrating optical engines with core computing chips, CPO significantly shortens electrical signal paths, creating new opportunities for optoelectronic co-design and system-level energy optimization.

Guided by an "integration-driven" evolutionary logic, the review systematically explores architecture evolution, key enabling technologies, and system applications. It first delineates the positioning and performance boundaries of Intensity Modulation/Direct Detection (IM/DD) and Coherent paradigms, emphasizing that both face increasing constraints from electro-optical interfaces and packaging parasitics as data rates climb. The discussion then details the technology chains for transmitters and receivers, analyzing co-design strategies for mainstream schemes like VCSEL, EML, MZM, and MRM drivers, as well as the integration of PIN photodetectors (such as GeSi and GaAs) with TIA front-ends.

In terms of applications, the review focuses on Data Center and HPC interconnects while extending its scope to short-reach links such as optical wireless and emerging frontiers like IoT, edge computing, autonomous driving, and quantum communication. This breadth illustrates the transition of integrated transceivers from discrete modules to reusable optoelectronic interfaces. Synthesizing the roadmap of photonic integration platforms and advanced DSP methodologies, the article charts the trajectory toward future high-density optoelectronic engines, emphasizing that performance gains will increasingly rely on full-stack co-optimization across device, circuit, packaging, and system levels.

Synthesizing research across device, circuit, packaging, and system levels within a unified framework, this review maps out the current technological landscape of integrated optical transceivers. It highlights that the field is transitioning from a focus on single-device optimization to a new era of system-level co-design. Looking ahead, driven by advancements in Co-Packaged Optics (CPO) and Chiplet technologies, silicon photonics and heterogeneous integration platforms are poised to reshape optoelectronic interfaces. By breaking through bandwidth and energy efficiency bottlenecks, these technologies will construct the high-speed all-optical infrastructure underpinning the future intelligent world.

Keywords: integrated optical transceiver, co-packaged optics, optical input/output, optical interconnects

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His research team focuses on frontier technologies in integrated photonics, dedicated to the research of high-performance photonic integrated devices and applications. His research scope covers high-speed optical communications, LiDAR, and optical computing, where he has achieved significant progress in high-performance silicon-based photonic devices and integrated systems. Over the past five years, as the first or corresponding author, he has published over 200 papers in high-impact journals such as Nature (3 papers), Nature Photonics, and Nature Communications (10 papers). His representative achievements have been recognized with numerous awards, including China's Top 10 Scientific and Technological Innovations Award, China's Top 10 Advances in Information and Communication Technology (twice), China's Top 10 Optical Advances, China's Top 10 Social Impact Events in Optics (twice), and China's Top 10 Advances in Chip Science. He also received the 2024 Beijing Natural Science Award First Prize (ranked first).

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