

Development and Application of Silicon Photonics Technology



Overview

The emerging applications of silicon photonics Silicon photonics (SiP) has rapidly evolved from data-communication technology into a broadly enabling platf.

Key Takeaways

Silicon photonics has evolved from early experimental devices to a mainstream technology enabling high-performance photonic integrated circuits for communications, computing, and sensing applications.

Historical Evolution

Silicon photonics began in the mid-1980s with the introduction of silicon-based photonic integrated circuits (PICs) and the demonstration of low-loss waveguides on silicon-on-insulator (SOI) substrates in the early 1990s. Initial devices included high-speed pn junction modulators and photodetectors, marking the small-scale integration (SSI) era with only a few components per PIC. The technology progressed to medium-scale integration (MSI) with 10-500 components, enabling commercial adoption in data center transceivers using Mach-Zehnder modulators and microring modulators.

Technological Foundations



Silicon photonics leverages the mature silicon semiconductor fabrication ecosystem, allowing high-yield, low-cost production of PICs with nanometer-level precision. The core technology uses SOI wafers, where a silicon layer atop a buried oxide layer forms waveguides for optical signals. Silicon nitride layers are increasingly integrated to enhance performance and design flexibility.

Devices exploit nonlinear optical effects such as the Kerr effect, Raman scattering, and two-photon absorption, enabling wavelength conversion, all-optical signal routing, and advanced modulation schemes.

Commercialization and Foundry Ecosystem

The commercial silicon photonics ecosystem includes designers, foundries, and integrators. Foundries now provide process design kits (PDKs) with standardized, optimized photonic elements, facilitating reproducible and scalable device fabrication. Current production occurs in 200mm and 300mm CMOS-compatible facilities, supporting high-volume manufacturing with precise control over device dimensions and performance.

Applications and Emerging Trends

Silicon photonics is widely used in optical communications, particularly in data center interconnects, where it enables high-bandwidth, energy-efficient transceivers. Beyond communications, applications are expanding to optical computing, LiDAR, biosensing, microwave photonics, and quantum computing. Integration with artificial intelligence and photonic neural networks is emerging, offering improved efficiency for complex data processing tasks.

Future development focuses on heterogeneous integration, large-scale PICs, and hybrid silicon-photonic platforms to increase functionality and unit shipments from millions to billions.

Challenges and Future Directions

Key challenges include integration and packaging bottlenecks, thermal management, and scaling to very-large-scale integration (VLSI) of photonic circuits. Research is addressing these through multi-layer waveguides, heterogeneous integration of III-V lasers, and advanced device engineering. Roadmaps for next-generation silicon photonics aim to expand applications in sensing, computing, and communications while maintaining CMOS-foundry compatibility.

Silicon photonics continues to bridge the gap between electronics and photonics, offering a scalable, high-performance platform for the next generation of optical technologies.

Article Content

The emerging applications of silicon photonics

Silicon photonics (SiP) has rapidly evolved from data-communication technology into a broadly enabling platform for modern physics and engineering.

Review of Silicon Photonics Technology and Platform Development

We will provide a comprehensive review of the development of silicon photonics and the foundry services which enable the productization, including various efforts to develop and release PDK devices.

Silicon Photonics

Owing to the fast development in the last decade, the research of silicon photonics now covers a large area. Fig. 50 shows a tree plot of the research field of silicon photonics in on-chip photonic signaling

Silicon photonics

Silicon photonic devices can be made using existing semiconductor fabrication techniques, and because silicon is already used as the substrate for most integrated circuits, it is possible to create hybrid

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Silicon photonics is breaking the physical limits of light-based information processing. By merging CMOS scalability with heterogeneous integration and optoelectronic co-design, it enables

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We chart the generational trends in silicon photonics technology, drawing parallels from the generational definitions of CMOS technology. We identify the crucial challenges that must be...

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In the past decade, we have witnessed the rapid development of silicon photonics, especially in heterogeneous material integration, the trend towards system integration, and the expansion of

The perspective of all-silicon photonics and systems

We provide a comprehensive perspective on advancing high-performance all-silicon photonic devices and systems. By fully leveraging the inherent potential of silicon, diverse

SILICON PHOTONICS

The versatility of silicon photonics technology allows for applications beyond transceivers and optical interconnects. More than 200 silicon photonics startups are developing products to meet the

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Introduction to Photonic Integrated Circuits and PIC Technology

The concept of the photonic integrated circuit is similar to the concept of electronic integrated circuits. However, electronic integrated circuits integrate transistors, capacitors, resistors,

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Silicon Photonics 2018

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