Systems-on-chip in monolithically integrated silica-on-silicon platform

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ABSTRACT

We introduce cutting-edge monolithically integrated photonic designs realized in a high-performance silica-on-silicon planar lightwave circuit (PLC) platform. Systems-on-chip require integration from a dozen to a few hundred optical functions, necessitating component and wafer level optimizations. Our closed-loop feedback framework enables us to achieve low propagation losses (<0.009 dB/cm), efficient fiber coupling (0.5 dB/facet), temperature stability (< 10 pm/°C), wavelength-independent operation, as well as tight polarization and phase control. Due to the lack of two-photon absorption, low scattering, and negligible absorption, our silica-on-silicon platform is well-suited for high-pump power applications in LiDAR and accelerated computing. We discuss how these characteristics allow us to monolithically integrate high-performance optical building blocks such as K-clocks, cascaded lattice filters, polarization-beam splitters, and optical hybrid components into systems-on-chip for advanced photonics applications. We demonstrate the versatility and robustness of the platform by discussing examples of monolithically integrated chips used in AI/computing accelerators, and advanced vision applications based on LiDAR. Based on exceptional optical characteristics achieved through our platform, our systems-on-chip have emerged as high-performance and scalable solutions, capable of meeting the rigorous demands imposed by a wide range of applications.

Keywords: LiDAR, accelerated optical computing, k-clock, delay lines, planar lightwave circuit, silica-on-silicon, integrated optics

1. INTRODUCTION

Recent advancements in high-speed communication, accelerated computing, and advanced vision systems have become possible due to integrated photonics.[1,2] While there are several commercially available integrated platforms, silica-on-silicon planar lightwave circuit (PLC) technology stands out as a versatile and low-cost platform with powerful characteristics. These include ultra-low propagation losses, efficient fiber coupling, unmatched polarization and phase control, excellent reliability, and mature fabrication. Most recently, it has been recognized that the silica-on-silicon platform is capable of handling optical intensities that are orders of magnitude higher than in other platforms. This has allowed the silica-on-silicon platform to reach widespread applications ranging from optical computing/AI accelerators to long-range LiDAR.

In this paper, we describe how the unique properties of the silica-on-silicon platform can be leveraged to produce individual building blocks and then combine these blocks into large-scale photonic systems. We identify the key platform capabilities that are essential for building systems-on-chip for advanced photonics applications.

2. SILICA-ON-SILICON PLC PLATFORM

We build systems-on-chip using buried silica-based waveguides with typical dimensions of 3.0×3.0 μm and a refractive index contrast of $\Delta n = 2.0\%$. The fabrication is done using standard atmospheric pressure chemical vapor deposition (APCVD) and reactive ion etching processes. We have previously reported[3] on interferometric devices that contain meters-long delay lines with propagation losses of <0.01 dB/cm and wavelength-independent operation. Low-loss fiber-matched mode converters (<0.5 dB per facet), temperature-stable operation (< 10 pm/°C), and consistent performance are simultaneously achieved across entire optical communication bands. Due to the absence of non-linear effects and two-photon absorption, the silica-on-silicon platform is ideally suited for building applications that use high-power optical pumps, such as optical backbones in accelerated computing or long-range LiDAR systems for the automotive industry.

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We have developed architectural solutions that allow the densification of photonic functionality and have achieved compact arrangement of arbitrarily long interferometric structures in state-of-the-art multiplexers for coarse-wavelength division multiplexing (CWDM) and LAN-WDM applications.[4,5] Comprehensive optimizations of our process and design parameters allow us to realize a wide variety of passive devices including arrayed waveguide grating (AWG) designs, coherent systems, and cascaded lattice filters. In addition to their high optical performance characteristics, the designs have proven to be remarkably robust in volume manufacturing, resulting in their large-scale deployments in commercial applications.

3. SYSTEMS-ON-CHIP

An important drawback of silicon photonics is that, in near-IR, two-photon absorption significantly attenuates optical power. In silicon, two-photon absorption becomes a source of free-carrier absorption and free-carrier dispersion[6,7]. While SiN waveguides do not experience two-photon absorption, the presence of strong non-linear effects also restricts the use of the SiN technology in high-power applications. Silica-on-silicon platform has neither two-photon absorption nor significant optical non-linearities making it ideally suited for high-optical power applications in optical computing and long-range LiDARs.

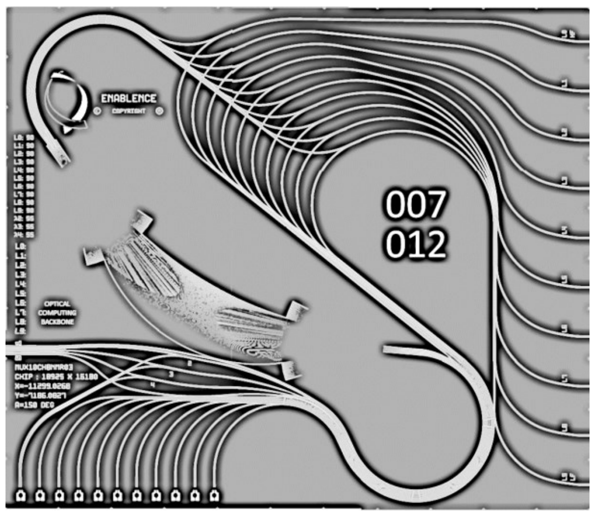

Figure 1. System-on-chip used in optical computing accelerator. The chip aggregates 10 laser pumps onto a single output while providing monitoring of both power and wavelength independently.

Figure 1 shows an example of a silica-on-silicon system-on-chip used in optical computing accelerators. The chip was specifically designed to aggregate optical power coming from 10 pump sources with distinct wavelengths while providing a feedback loop for adjusting both the power and the wavelength of each source. The chip was fabricated in the silica-on-silicon platform and allows to control and deliver over > 1 Watt of optical power to the accelerator unit.

To maintain the power stability of the pump sources, the system-on-chip shown in Figure 1 incorporates a series of optical taps that follow the input guides (the right edge of the chip) before they are multiplexed using an arrayed waveguide grating (AWG). In addition to the optical taps that precede the AWG, the system allows us to ascertain the wavelength of individual pumps by providing a series of taps that are located post-AWG. This is accomplished by a weak current dithering of each pump at a predefined frequency in the 1 kHz range. When this dithered signal convolves with the passband of the AWG, the slope of the intensity change relative to the current change can be used to determine the wavelength compared to that of the AWG. Since each of the pump sources has a unique dithering frequency, it becomes possible to discriminate between a superposition of all channels by merely looking at the peak intensities of the Fourier-transformed signal.

Figure 2 shows an industrial LiDAR system-on-chip that incorporates dozens of optical elements to incorporate not only a strong wavelength-modulated pump source but also a high-dynamic range detection system. LiDAR often relies on polarization beam splitters (PBSs) with each chip containing several to a few dozen PBSs. LiDAR systems measure the signal in the momentum (k)-space, which is linear to the change in optical frequency of the swept source. Therefore, the precision and reliability of LiDAR systems depend on the quality and stability of the k-clock reference system that is based on meters-long asymmetric interferometers with a frequency response in the 10 MHz range (bottom section of the chip). The k-clocks can only be realized in the platforms that simultaneously possess ultra-low propagation losses and high-polarization maintenance stability. The low propagation losses and tight polarization control make the monolithic integration of k-clocks straightforward in a silica-on-silicon platform.

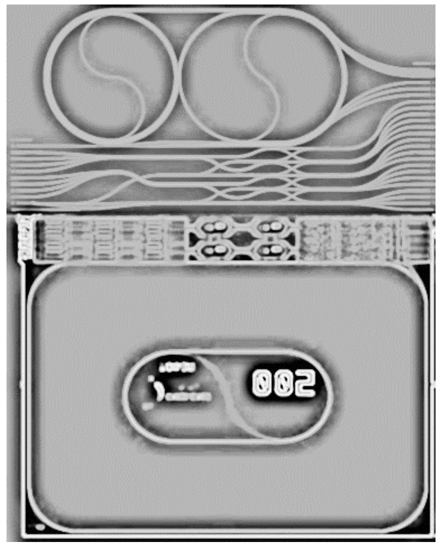

Figure 2. Industrial LIDAR system-on-chip with monolithically integrated k-clock (bottom section) and coaxial transmitter/receiver functionality.

4. CONCLUSIONS

We demonstrate that the silica-on-silicon PLC platform is ideally suited for applications that incorporate high-power optical pumps, such as the ones used in advanced vision and optical computing accelerators. We demonstrate that the PLC platform can be leveraged to build systems-on-chip that incorporate a large number of wavelength and polarization management components that require ultra-low propagation losses, efficient fiber coupling, temperature stability, and phase control.

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