Heterogeneous Integration as a Manufacturing Platform for Photonic Integrated Circuits

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Abstract

Heterogeneous integration enables all the elements of photonic systems to be fabricated on a single chip with the cost structure of silicon foundries allowing photonic integrated circuits to meet the complexity, volume and cost requirements of the next generation of communication systems.

INTRODUCTION

Photonic integration has the potential to meet the requisite cost, complexity, performance and manufacturing volume needs of future communications systems. The most obvious benefit of integration is the direct reduction in size, weight, power, and cost that results from integrating chip-scale photonics and electronics in a semiconductor wafer process. Integration can also increase the reliability, stability, and robustness of photonic systems with the elimination of discreetly packaged optical components.

PHOTONIC INTEGRATION PLATFORMS

Traditionally, photonic integration has been broken down into two categories: planar lightwave circuits (PLCs) made of SiO_2-based materials and largely used for integrating passive devices such as optical filters and multiplexors, and photonic integrated circuits (PICs) made of InP-based materials used for integrating active devices such as lasers, modulators, and photodetectors. The high temperature processing and large size of PLCs limit this platform to a few photonic functions and PLCs have not evolved much in function or scale over the last decade. In contrast InP-based PICs are continuing to improve in performance and lead the state-of-the-art in photonic functionality on a single chip.

InP-based PICs have ideal material properties for telecom/datacom wavelength diverse light emission, modulation, and detection, but have the detriment of relying custom fabs with small (2-4") wafers.

More recently, Si has been identified as a PIC material capable of integrating nearly all photonic functions on a single platform, with the exception of the optical gain. The ability to integrate low loss waveguides with modulators, detectors, and even CMOS electronics makes silicon photonics quite attractive as a photonic platform. Silicon photonics also has the benefit of leveraging the costs of using large wafers and the significant wafer processing infrastructure that already exists due to CMOS electronics development. Furthermore, by using standard silicon wafer processes, Si photonics can adapt to and leverage the vast packaging infrastructure developed for high performance electrical systems-in-package.

While most photonic functions can be implemented on a Si platform, however, the lack of light generation and amplification limits the complexity of silicon PICs and the applications they can address. Meeting next generation photonic systems needs requires an integrated photonic platform which possesses all photonic functions and can enable cost-effective photonic fabrication. In other words, what is needed is a photonic platform with the active component performance and wavelength diversity of InP PICs with the passive component performance, available fabrication and packaging infrastructure, and cost of silicon PICs.

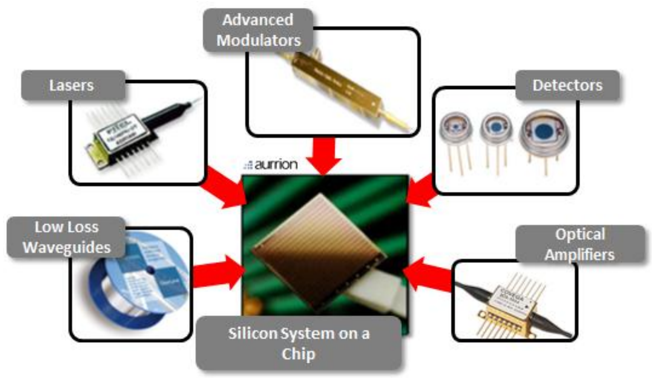

FIGURE 1
HETEROGENEOUS INTEGRATION: COMPLETE PHOTONIC LIBRARY ON A SILICON PHOTONICS PLATFORM.

HETEROGENEOUS INTEGRATION

Aurrion's heterogeneous photonic technology achieves InP performance and functionality on a silicon platform. The basic underlying Si photonic circuit is generated using an established foundry infrastructure, providing cost advantage from leveraging shared resources, 200mm wafers and yield improvements from advanced process tooling. [1]

The InP functionality is then added to the circuits on a wafer-scale using Aurrion's heterogeneous integration process, a step that is similar to the bonding process being introduced into MEMs commercial devices. Hence, Aurrion can leverage best-in-class performance based on bonded III-V active devices, silicon and silicon nitride waveguides, grown germanium, and silicon P-N junctions, as well as its choice of advanced electronic chip technologies for device drivers. The result is a complete photonic platform as shown in Figure 1.

The active devices enabled by the heterogeneous integration process are a combination of the underlying silicon photonic waveguide structures and the bonded III-V epitaxial layers. As shown schematically in Figure 2, unprocessed material is bonded to a silicon photonics wafer. Multiple epitaxial materials, such as designs for a laser and a modulator or a detector and an amplifier, can be used. The devices are then formed using the lithographic process, so there is no critical alignment to the underlying waveguide.

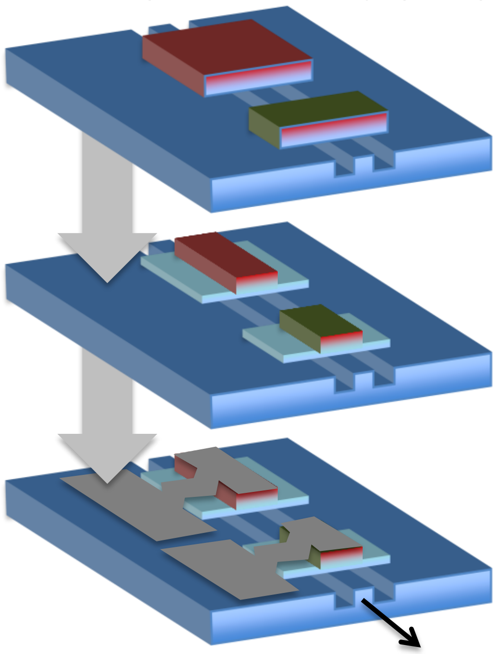

FIGURE 2
INTEGRATION OF III-V MATERIALS ON TO SILICON PHOTONICS TO FORM ACTIVE DEVICES.

GAIN FOR SILICON PHOTONICS

Heterogeneous integration, therefore, enables the critical missing function on silicon photonics: light generation. Figure 3, for example, shows the performance of semiconductor optical amplifiers that exhibit a gain of 300dB/cm.

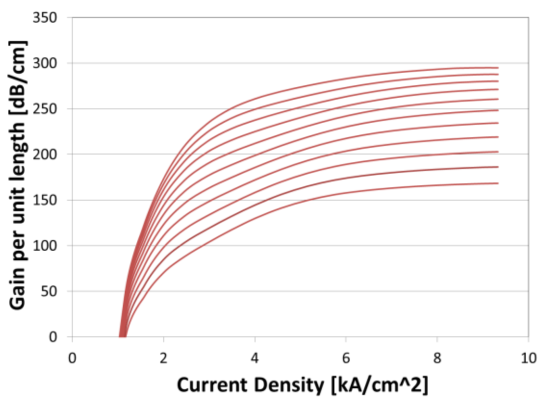

FIGURE 3
GAIN CURVES FOR SEMICONDUCTOR OPTICAL AMPLIFIERS FABRICATION BY AURRION ON SILICON USING HETEROGEOUS INTEGRATION.

These gain blocks can be combined with feedback structures in the silicon such as gratings to create lasers. These lasers have demonstrated continuous wave (CW) optical output power of 45 mW at room temperature and still >10mW at 70C as shown in Figure 4.

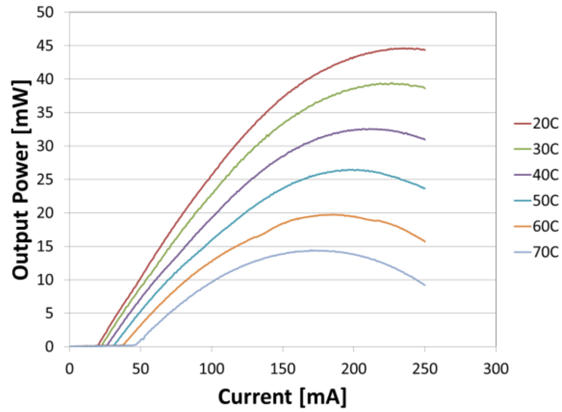

FIGURE 4
LIGHT-CURRENT CURVE FOR AN AURRION LASER FABRICATED ON SILICON USING THE HETEROGENEOUS INTEGRATION PROCESS.

Leveraging a high yield foundry infrastructure, these devices can be made in arrays, combined with silicon-based modulators and either Ge or III-V based photodetectors to enable high bandwidth PICs for future interconnects at 1Tb/s and beyond.

CONCLUSIONS

The next generation of communication systems will have complexity, cost and volume requirements that are difficult to achieve with current integration technologies. The heterogeneous integration of III-V materials on to silicon photonics provides a flexible manufacturing platform for meeting this challenge.

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ACRONYMS

PIC: Photonic Integrated Circuit
PLC: Planar Lightwave Circuit