

Very Large Scale Integrated Photonics (VLSI-P)

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Abstract: We present on the demonstration of a number of critical device technologies including record low power modulators, tunable filters, and integrated lasers, along with the world's largest silicon photonic circuit, integrated on a 300mm platform.

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1. Introduction

Silicon photonics has been developed as a platform for low-power high-bandwidth communications, and the many impressive results on modulators [1-3], filters [4], and detectors [5], have produced considerable interest in the field for addressing the bandwidth and power consumption limitations within high-performance computers, data centers, and even on-chip communications. Yet, the silicon photonic platforms that have been developed are far more general in application than the communication-specific motivation for their development. Recent demonstrations in sensors, microwave-photonics, and optical phased arrays [6] have proven that silicon photonics represents a platform comparable to CMOS and MEMS in its widespread applicability.

Here, we present results from the first 300mm silicon photonics platform. Within the platform a number of key baseline technologies have been developed, including highly efficient modulators, tunable filters, germanium-on-silicon detectors, and even an on-chip CMOS compatible gain medium. These baseline technologies along with advanced modeling techniques are enabling large-scale photonic microsystem development. One recent example of a large-scale photonic microsystem implemented on this platform is our optical phased array work [6]. By building a “unit-cell” out of a coupler, phase-shifter, and compact grating-based emitters, we scaled nanophotonic phased arrays to a degree not previously envisioned, with 4096 “unit-cells” and 12,288 components overall, representing the largest silicon photonic circuit demonstrated to date. While phased arrays represent an important technology by themselves, enabling beam-steering and beam-forming, as well as the potential to implement truly holographic systems, perhaps the greatest impact of this recent demonstration lies in proving that very large-scale silicon photonic systems are not only possible, but relatively straightforward to implement. Future advances in communications, sensing, quantum, and microwave photonics will be enabled by advances in silicon photonics integration and the ability to accurately model large-scale silicon photonic circuits.

2. Design and Experimental Results

The baseline process flow that we have developed consists of 25-mask levels produced in a state-of-the-art 300mm CMOS fabrication facility. The layers include two etch-steps in the silicon, four implants, pure germanium, two levels of silicon nitride, erbium-doped aluminum oxide, two levels of copper interconnect, and two copper contact layers. From this platform, we have demonstrated the lowest power high-speed silicon modulators [3], wideband tunable filters [4] and phase shifters [7], four-port on-chip polarizing beam splitters [8], germanium detectors [5], and erbium-doped waveguide lasers [9]. One of the key results out of this platform is the demonstration of the first large-scale nanophotonic phased array (NPA) consisting of 64×64 optical nanoantennas on a silicon chip with all 4096 optical nanoantennas balanced in power and aligned in phase to produce a sophisticated radiation pattern, the MIT-logo, in the far field [6]. Since each unit cell consists of 3 components, namely a directional coupler, a phase shifter, and a grating emitter, the overall system consists of 12,288 elements. To our knowledge, this demonstration represents the largest coherent combination of nanophotonic elements to date. More importantly, it shows, that despite the short optical wavelength and corresponding length of the phase elements, the relative phase of the elements can be maintained, highlighting the ability to make arbitrary manipulations of the phase of an optical field within a microphotonic chip. The structure of the 64×64 OPA is schematically illustrated in Fig. 1a.

While this large-scale array was passive due to electrical pin-out limitations, an active 8×8 array was also produced, Fig. 1f, whereby the phase shifters were constructed from adiabatic bends with resistive heater sections built-in to the silicon waveguides, enabling direct heating of the silicon waveguides and producing a phase shift sufficiently large to contain the phase shift elements, coupling element, and a grating based emitter in a “unit cell” only a few wavelengths long. It is this “unit cell” that enabled the design to scale well beyond the results of past demonstrations, limited only by the number of electrical pin-outs [10]. This active phased array enables scanning of the optical beam in the x and y directions as well as the generation of additional beams in both directions. With integrated CMOS, this active array would enable nearly arbitrary beam formations in the far-field.

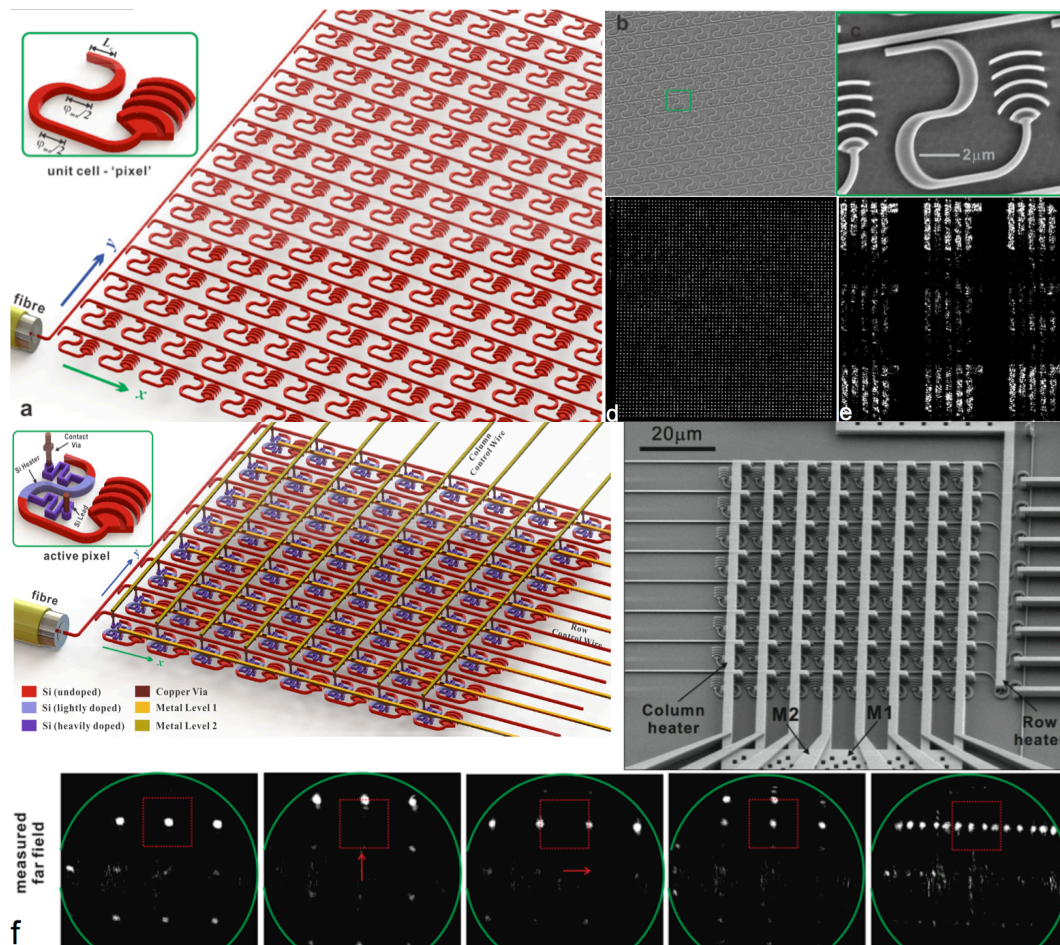


Figure 1 - Optical Phased Array (OPA) system. a) Schematic illustration of a 64×64 OPA system. Laser input from an optical fibre is equally delivered to each of the 4096 nanoantennas through silicon waveguides. Inset, schematic of a close-up view of one antenna unit cell (m, n), or 'pixel'. b) an SEM image of the array c) a close-up SEM of one pixel of the OPA system d) the near-field emission pattern, e) the far-field radiation pattern of the fabricated 64×64 OPA system and f) an active phased array showing beam-steering and beam-formation (bottom).

3. Conclusions

A 300mm silicon photonics platform has been developed with numerous baseline components including modulators, detectors, filters, phase shifters, emitters, polarization splitters and rotators, and even on-chip gain. Through careful design and rigorous modeling techniques, a few of these baseline components have been integrated into a "unit cell" enabling the first large-scale demonstration of a nanophotonic phased array. In the largest demonstration of its kind, 4096 "unit cells" were passively aligned in phase and excited from a single input waveguide to produce the MIT-logo in the far-field. A smaller, active phased array was also produced enabling free-form high-speed beam-steering. While the phased array application is an important one, it is likely that the greatest importance of the demonstration is in the scaling itself, with 12,288 components overall, the demonstration indicates for the first time that Moore's Law type scaling is possible in photonics. This work was supported in part by the Defense Advanced Research Projects Agency (DARPA) Microsystems Technology Office's (MTO) POEM and E-PHI programs.

4. References

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