Silicon Photonics for Low-Energy Optical Communications

To support the needs of the next generation of optical communications, researchers have developed a Sandia Silicon Photonics platform that leverages the semiconductor and nanotechnology capabilities of Sandia's Microsystems and Engineering Sciences Applications (MESA) complex to reduce the power dissipation of interconnects within digital systems.

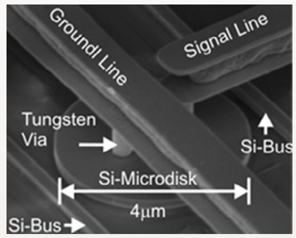
Improving Interconnection Performance

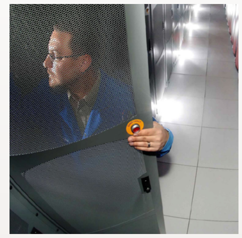
As integrated circuit chips now incorporate over a billion transistors, and single boards provide multi-teraflop (1012) computing capacity, the bandwidth and energy required to communicate data within and between integrated circuits are becoming a primary performance bottleneck. Information and communications technology (ICT) is responsible for up to 10% of US electricity consumption, with data centers responsible for about one fourth that total, and power consumption is projected to increase dramatically in the coming decades. Silicon photonics offers a potential breakthrough in optical interconnection performance, not just for supercomputer applications, but also for data communication and other applications. Importantly, silicon photonics can ride on the progress of silicon electronics and, when mature, will likely achieve the high yield, high reliability, and low costs common in the electronics industry.

Enabling Power Savings

Silicon photonics devices are comprised of silicon nanowire waveguides clad in silicon dioxide (SiO_2). The large refractive index contrast between the silicon waveguide and the oxide cladding allows light to be routed in the waveguide. Because the micro-disk resonators are so small, resonant electrically–controlled optical modulators can have capacitances as low as 20 femtofarads, and can operate with an electrical power usage of 3.2 femtojoules (fJ) per bit or lower, or 40 μW for 12.5 gigabits per second of information. This power savings is critical in high performance computing and satellite communications, especially for communications from cooled focal plane arrays. Preliminary cryogenic and radiation testing results suggest a promising future for silicon Photonics devices to operate in space.

Sandia has demonstrated many leading-edge silicon photonics devices for applications in communications, sensing, and computing. In addition to the optical resonant modulator described above, we have demonstrated silicon photonics optical switching building blocks for optical networks that may enable lower energy consumption in some applications by avoiding the optical to electrical to optical conversions that are part of optically interconnected electrically routed networks.





Fabricated chip from multi-project wafer run for CIAN (Cornell, UCSD, UC Berkeley, and U of Arizona)

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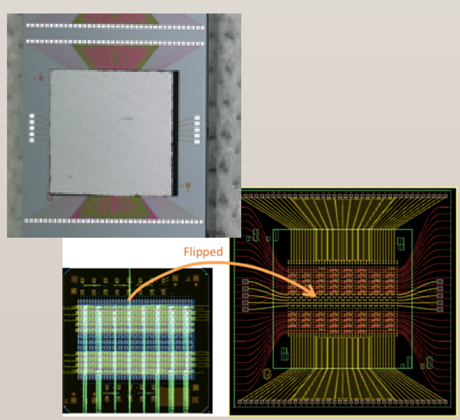
Commercialization Path

Sandia has a complete silicon photonics platform and the expertise to design silicon photonics devices for a variety of applications. We are actively seeking collaborators on photonics projects related to low-energy optical communications and computing, as well as other areas of importance for national security, such as RF signal processing, quantum computing, secure communication, sensing, and imaging.

We welcome discussions with academic and commercial entities interested in multi-project wafer (MPW) Si photonics fabrication runs for device prototyping and low-volume product manufacturing using our unique Si Photonics fabrication capabilities. Participants may utilize selected published Sandia photonic components in their prototypes and collaborate with our team to customize these designs or to co-develop novel concepts for their requirements. Interested parties may also collaborate with Sandia through Cooperative Research and Development Agreement (CRADA), Funds in Agreement (FIA), and in the upcoming Integrated Photonics Institute for Manufacturing Innovation (IPIMI).



Heterogeneous Integration of CMOS (top) and Silicon Photonics (bottom)

U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration
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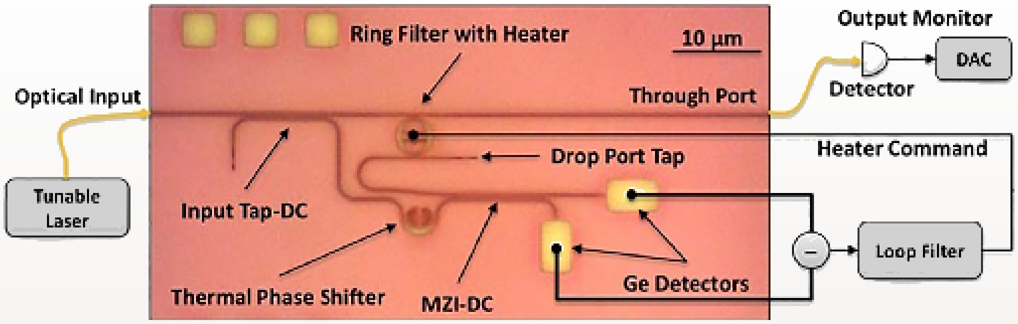
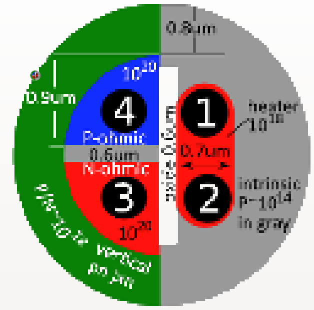




1, 2 – heater contacts
3, 4 – modulator contacts

Silicon Photonics Intellectual Property

Sandia National Laboratories has developed a portfolio of intellectual property in the area of silicon photonics, with 8 issued patents and 21 pending patents that are available for licensing. This portfolio includes several essential technologies for building low-power high-speed optical network: low-voltage, high-speed resonant modulator (with integrated heater for wavelength tuning), scalable methods for wavelength stabilization of resonant devices, high-speed Mach-Zehnder devices (including depletion-mode vertical p-n junction phase-modulator in MZ configuration, traveling wave carrier depletion MZ modulator, and thermo-optic MZ switch).

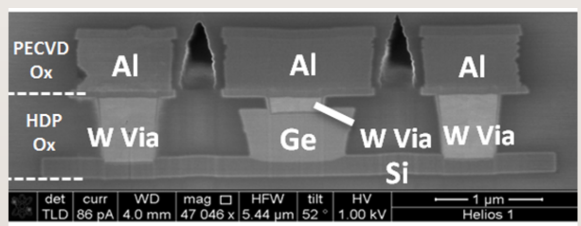
Number	Title
US 7,616,850	Wavelength-tunable Optical Ring Resonators
US 7,941,014	Optical Waveguide Device With An Adiabatically-Varying Width
US 7,983,517	Wavelength-tunable Optical Ring Resonators
US 8,027,587	Integrated Optic Vector-Matrix Multiplier
US 8,610,994	Silicon Photonics Thermal Phase Shifter With Reduced Temperature Range
US 8,615,173	Systems For Active Control of Integrated Resonant Optical Device Wavelength
US 8,625,939	Ultralow Loss Cavities and Waveguides Scattering Loss Cancellation
US 8,822,959	Method and Apparatus For Optical Phase Error Correction

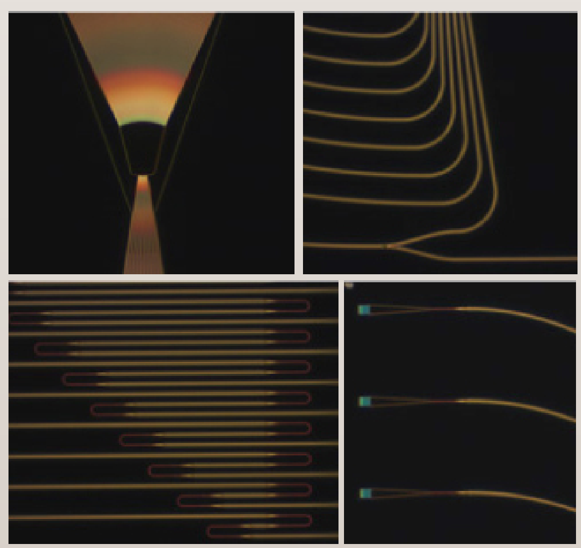
Above Left: Control of Integrated Micro-Resonator Wavelength via Balanced Homodyne Locking

Above Right: Silicon Photonic Modulator with Integrated Heater

Below Top: 45GHz Ge on Si Waveguide Coupled Photodetector

Below Bottom: Dark field images of fabricated nanowire waveguides, optical gratings, and lens.





Selected Publications:

1. C.T. DeRose, et.al., "A CMOS compatible external heater-modulator," IEEE Optical Interconnects Conf., 17-18 (2014).
2. J.A. Cox, et.al. "Control of Integrated Micro-Resonator Wavelength via Balanced Homodyne Locking," *Optics Express,* 22(9), 11279-11289 (2014).
3. W.A. Zortman, et.al. "Bit-Error-Rate Monitoring for Active Wavelength Control of Resonant Modulators," *IEEE Micro,* 33(1), 42-52 (2013).
4. A.M. Jones, et.al. "Ultra-Low Crosstalk, CMOS Compatible Waveguide Crossings for Densely Integrated Photonic Interconnection Networks," *Optics Express,* 21 (10), 12002-12013 (2013).
5. C.T. DeRose, et.al. "Ultra compact 45 GHz CMOS compatible Germanium waveguide photodiode with low dark current," *Optics Express,* 19(25), pp. 24897-24904 (2011).
6. W. Zortman, et.al. "Low-voltage differentially-signaled modulators," *Optics Express,* 19 (27), 26017-26026 (2011).
7. W. Zortman, et.al. "Integrated CMOS Compatible Low Power 10Gbps Silicon Photonic Heater Modulator," in Optical Fiber Comm. Conf., OSA Technical Digest (Optical Society of America, 2012), paper OW4I.5.
8. M. Watts, et.al. "Vertical junction silicon microdisk modulators and switches," *Optics Express,* 19, 21989-22003 (2011).

For additional information, visit our website at: www.sandia.gov/mstc

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