Silicon Photonics in High Performance Computing

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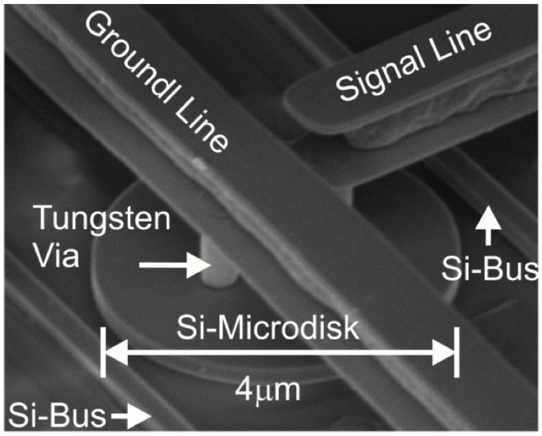
Communications links on high performance computers currently use electrical or directly modulated laser optical communication links and multi-mode fibers. However, neither electrical lines nor multi-mode fibers offer enough bandwidth at a sufficiently low cost or power for future, exascale, high-performance computers. Such machines will require wavelength division multiplexing (WDM) in order to provide high-bandwidth, low-cost and low-power communications to the server nodes. Silicon photonic communication networks offer substantial promise for addressing these needs.

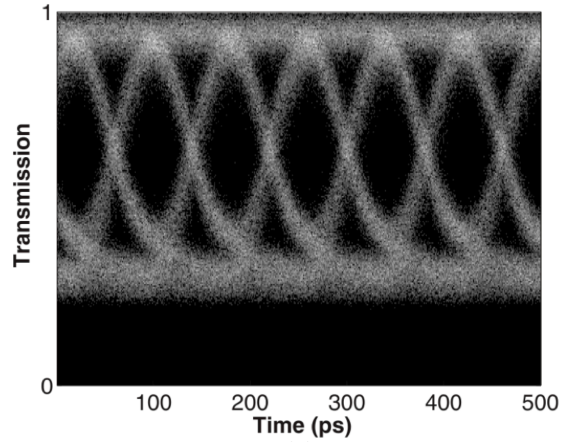
In this talk, we present an overview of our progress towards the implementation of silicon photonics in high performance computing. Our approach utilizes resonant silicon modulators to implement a WDM transmitter, microring-resonator filters to demultiplex WDM channels, and germanium detectors to receive the demultiplexed signals. While many silicon modulators have been implemented [1-3], by using resonance in conjunction with tight confinement and a vertical *p-n* junction [4], we have achieved <10fJ/bit power consumption [5], to our knowledge a new record for ultra-low power silicon modulators. Moreover, by using an AC-coupled drive we have demonstrated devices that operate on only 1-to-1.5V peak-to-peak, enabling direct drive from standard CMOS electronics (see Fig. 1a and 1b). Further, we have demonstrated the ability to control the resonant frequency of the microdisks across widely-varying temperature excursions [6] (see Fig. 1c and 1d), a feat necessary for compensating the large temperature dependence of silicon microresonators. Finally, on the receive-side, we have demonstrated germanium-on-silicon detectors with low dark current, however, device yield remains an active area of research.

While many challenges remain, in all, we believe we have constructed a viable approach that addresses many of the challenges facing the communications, power, and cost bottlenecks of future Exascale high performance computers.

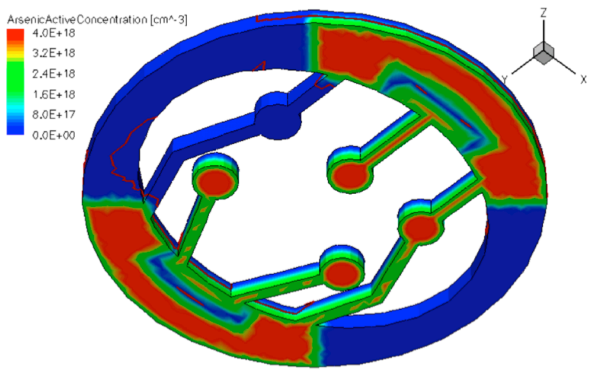
1. William M. Green, Michael J. Rooks, Lidija Sekaric, and Yurii A. Vlasov, "Ultracompact, low RF power, 10 Gb/s silicon Mach-Zehnder modulator," Optics Express, **15**, p. 17106 (2007)
2. A. Liu, R. Jones, L. Liao, D. Samara-Rubio, D. Rubin, O. Cohen, R. Nicolaescu, and M. Paniccia, "A high-speed silicon optical modulator based on a metal-oxide-semiconductor capacitor," Nature **427**, 615-618 (2004)
3. Q. Xu, B. Schmidt, S. Pradhan and M. Lipson, "Micrometre-scale silicon electro-optic modulator," *Nature* **435**, 325-327 (2005)
4. M. R. Watts, D. C. Trotter, and R. W. Young, "Maximally Confined High-Speed Second-Order Silicon Microdisk Switches," *OFC 2008* PDP14
5. W. A. Zortman, M. R. Watts, D. C. Trotter, R. W. Young and A. L. Lentine, "Low-Power High-Speed Silicon Microdisk Modulators," *Submitted, Conference on Lasers and Electro-Optics (CLEO)*, San Jose CA (2010).
6. C. T. DeRose, M. R. Watts, D. C. Trotter, D. L. Luck, G. N. Nielson and R. W. Young, "Silicon Microring Modulator with Integrated Heater and Temperature Sensor for Thermal Control," *Submitted, Conference on Lasers and Electro-Optics (CLEO)*, San Jose CA (2010).



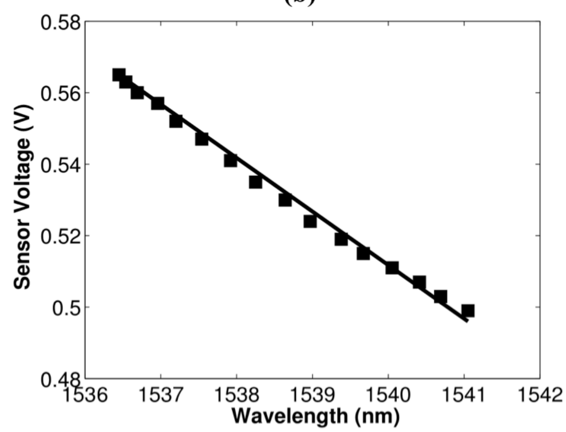
(a)



(b)



(c)



(d)

Fig 1: (a) A scanning electron micrograph (SEM) of a 4um microdisk modulator where the oxide encasing the disk has been removed for viewing purposes. The disk is electrically contacted in its center using standard CMOS tungsten vias. (b) A 12Gb/s eye-diagram from a 3.5um microdisk modulator, AC-coupled, to enable a low, 1.5V drive. (c) An adiabatic microring-ring modulator with an integrated heater and temperature sensor for controlling the resonant wavelength. (d) A measurement of the sensor voltage in (c) versus wavelength as the resonator is heated. The measurements demonstrate a near linear relationship between sensor voltage and resonant wavelength.