Hacking CMOS: Electronics, Photonics, Ionics, Fluidics

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Here, we show that CMOS manufacturing infrastructure and design rules support a host of functions and applications beyond electronics - to include nanoscale photonics, ionics, and fluidics. For example, the thin silicon layers that comprise the body of a silicon transistor can be repurposed to realize a full suite of infrared waveguides, optical resonators, high-speed optical modulators and detectors. By adhering to the structural design rules dictated by the silicon fab, these nanophotonic elements can be embedded with intelligence and scaled to VLSI complexity for consumer applications and cost. Our recent work has extended this CMOS photonics platform across wavelengths from UV to IR and applications from quantum computing to molecular sensing. The complexity of CMOS lies both within the silicon layer and within the metal wiring that interconnects the billions of transistors together. We have recently demonstrated that these metal layers and the high-quality dielectrics between them can support electric fields that trap and manipulate single charged atoms (ions). We have demonstrated long-term trapping of single ions as well as arrays of ions in a vacuum above the chip surface. The isolation of the ions from solid surfaces preserves their quantum coherence. Further integration of these ionic devices with photonics enables a class of high-fidelity quantum logic and precise atomic clocks that can be integrated at the chip scale. Finally, the dielectric structures that surround and isolate individual transistors can be utilized to realize nanometer size templates for self-assembly at gigascales. We have recently demonstrated nanofluidic components that utilize the transistor dielectrics as fluid channels with femtoliter volumes fabricated alongside sensitive electronics and photonics. Such a platform may one day enable manipulation and measurement at the scale of single molecules with parallelism reaching billions of simultaneous measurements.

The most important aspect of the technology and examples above is that these nanoscale structures in silicon, copper, and glass are available to the public. We utilize open foundries (such as MOSIS) that support many users sharing the cost of fabrication. Our nanoscale photonics, ionics, and fluidics are realized next to the electronic circuits designed by small and large companies, students from around the world, and people who just like to tinker. They are the machine shops of the nano-era.

Rajeev J. Ram has worked in the areas of physical optics and electronics for much of his career. In the early 1990's, he developed the III-V wafer bonding technology that led to record brightness light emitting devices at Hewlett-Packard Laboratory (Lumileds) in Palo Alto. While at HP Labs, he worked on the first commercial deployment of vertical cavity surface emitting lasers. He developed semiconductor lasers without population inversion, semiconductor lasers that employ condensation of massive particles (polariton lasers), and threshold-less lasers. Since 1997, Ram has been on the Electrical Engineering and Computer Science faculty at the Massachusetts Institute of Technology (MIT) and a member of the Research Laboratory of Electronics and the Microsystems Technology Laboratory. He has served on the Defense Sciences Research Council advising DARPA on new areas for investment and served as a Program Director at the newly founded Advanced Research Project Agency-Energy. His group at MIT has developed energy-efficient photonics for microprocessor systems, microfluidic systems for the control of cellular metabolism, and record-efficiency light sources. He co-founded AyarLabs which provides optical I/O for integrated electronics and ERBI Biosystems which develops microbioreactors for automated cell culture. He is a MacVicar Faculty Fellow, a Bose Research Fellow at MIT, and a Fellow of the Optical Society of America and IEEE Fellow.