From Nanodevices to Nanosystems: The Carbon Nanotube Case Study

Max M. Shulaker*, H.-S. Philip Wong, Subhasish Mitra
Stanford University, Stanford, CA, 94305
*maxms@stanford.edu

Emerging nanomaterials, such as carbon nanotubes (CNTs), have great potential to revolutionize future electronic systems. For instance, carbon nanotube field-effect transistors (CNFETs) are projected to improve the energy efficiency of digital systems by an order of magnitude compared to silicon CMOS. It was commonly believed that CNTs face major obstacles such as substantial imperfections and variations inherent to CNTs, and low CNFET current densities; and that these obstacles limited CNFET demonstrations to stand-alone transistors or logic gates, with severely limited performance, yield, and scalability. In this talk, I will describe how to overcome these challenges through a combination of new CNT processing and CNFET circuit design solutions. This new approach transforms CNTs from solely a scientifically-interesting material to working nanosystems such as the first microprocessor and the first digital subsystems built entirely using CNFETs. These are the first system-level demonstrations among promising emerging nanotechnologies for high performance and highly energy-efficient digital systems. I will also demonstrate the highest current-drive CNFETs to-date, which are, for the first time, competitive with comparably-sized silicon-based transistors available from commercial foundries.

I will also discuss how CNTs are naturally suited for enabling new system architectures, such as monolithically-integrated three-dimensional (3D) integrated circuits. Monolithic 3D integration allows for computation immersed in memory by creating massive connectivity between vertically-interleaved layers of logic and memory. Such architectures are key to achieving high energy efficiency for emerging abundant-data applications. I will demonstrate the first monolithically-integrated 3D nanosystems combining arbitrary vertical interleaving layers of emerging memories (Resistive RAM) and CNFET-based digital logic, fabricated directly over a silicon CMOS substrate.