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FRONTIERS OF MOLECULAR ENGINEERING

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Today, engineers and scientists at Columbia are working together to create and understand electronic components at the nanometer scale using novel materials. The drive to miniaturize components of electronic circuits, and more specifically, the transistor, has come a long way since its invention in the mid 40s. It took about three decades for circuit building blocks to feature prominently in devices made by Intel and other manufacturers. By 2010, Intel had developed a processor, which had over a billion transistors. Today, the size of a transistor has scaled down by a million to a size that is under 20 nm. Although this is a great achievement, my lab is focused on going beyond these realizations. We hope to show that circuit building blocks can be created using molecular components. Indeed, in 2009, we demonstrated that one could make a single-molecule switch that toggles between on and off through mechanical trigger. This is just one example of the work we have carried out.

The research in my lab focuses on developing and using novel instruments to make and study circuits where the functional element is a single-molecule. There are many challenges that have to be overcome to successfully create such devices, primarily because one cannot "see" or even image with advanced microscopes, a single-molecule circuit. More importantly, our work is highly interdisciplinary. We collaborate with chemists who synthesize molecules for the circuits, and apply our engineering and physics knowledge to build instruments for the measurements. Through this collaboration, we demonstrated that we could make a potentiometer (a pot, for any electrical engineers in the audience) using a single-molecule.

Over the past few years, my group, driven by incredibly talented SEAS graduate students, has developed methods to not only measure the current that flows across a single molecule, but also the force required to break such a circuit and the amount of electricity one can generate using heat in these devices. We are now trying to see if we can control these circuits with light. Overall, our work provides a fundamental understanding of electronic properties at the nanometer scale, and this impacts a wide range of areas from solar energy, flexible electronics to biological processes including photosynthesis and respiration.

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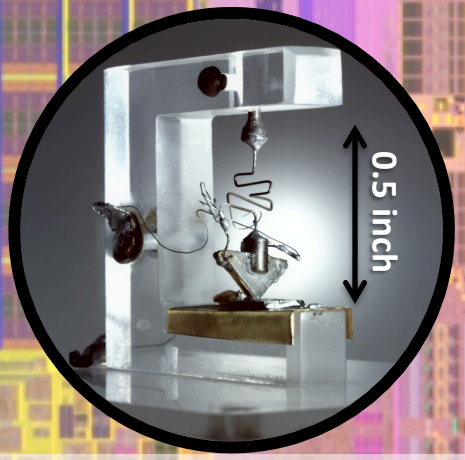
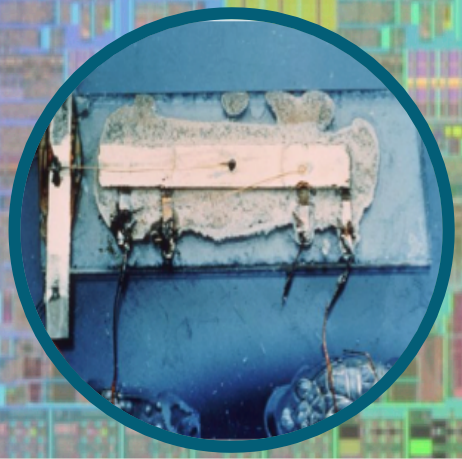
Vision:
Developing next generation electronic circuit components with molecular building blocks at unchartered length scale close to fundamental limit

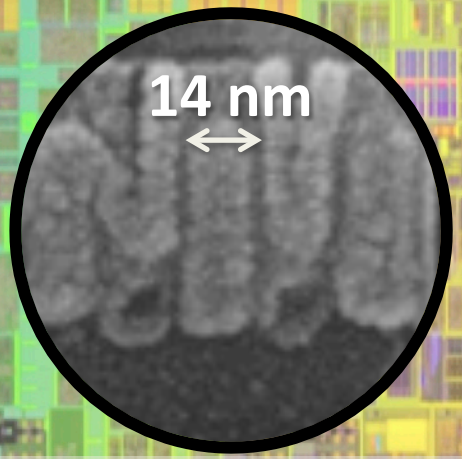
Intel core i7 2010



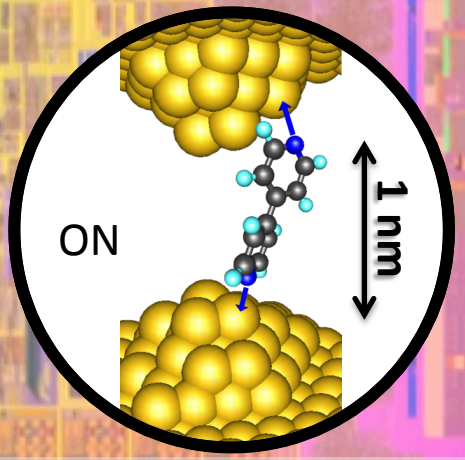
First transistor, Bell Labs 1946



First IC, Texas Inst 1958



Transistor, Intel 2014



Single-molecule Switch

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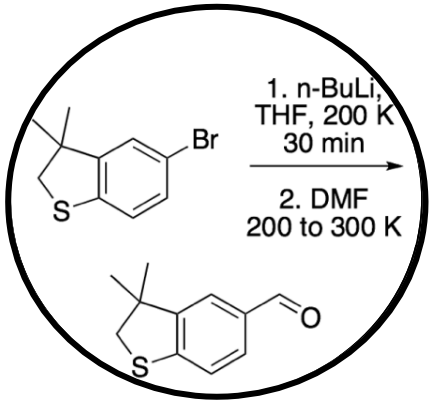
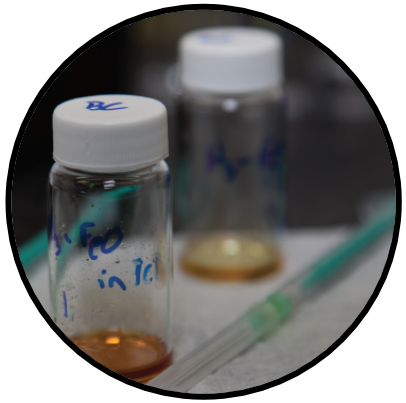
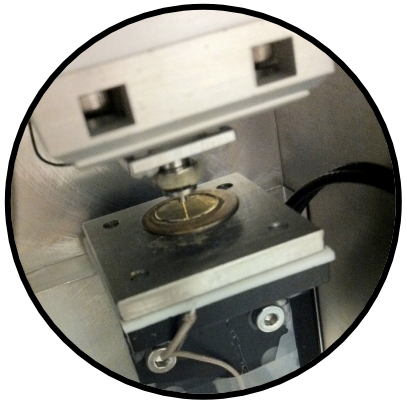
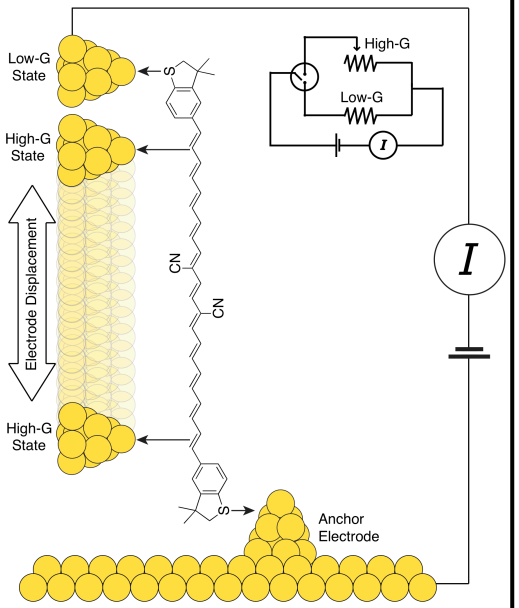
Approach:
Interdisciplinary research: physics, chemistry & engineering -- to fabricate nanoscale electronic devices







Single-molecule Potentiometer



Venkataraman & Nuckolls collaboration. Nano Letters. 2011

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Approach:

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Impact:
Novel devices with properties unique to their size; basic science understanding of conduction from energy to photosynthesis