New Materials to Push the Limits of Moore's Law

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Although the end of Moore's law has been predicted by many for decades, the terrific work of Silicon device engineers has been able to push silicon transistors to nanometer-dimensions. However, the end of silicon transistors, as we know them, is quickly approaching. On one hand, band-to-band tunneling is expected to dominate leakage for Silicon transistors with gate lengths below 9 nm. At the same time, the limited density-of-states of silicon makes source and drain contacts with ultra-low resistance extremely challenging. Unfortunately, none of the narrow bandgap materials (e.g. InAs) that have traditionally been investigated for these gate lengths, are able to solve these key challenges. In this talk, we will present some of the work that my group at MIT is doing to, on one hand, extend Moore's law and, on the other, enhance the functionality of Silicon chips in a more-than-Moore approach.

The extremely high carrier mobility of many narrow bandgap semiconductors has motivated for many years their study as channel materials in highly scaled transistors. These narrow bandgap and low effective mass are however responsible for the very high band-to-band tunneling current predicted in highly scaled devices. It will be very challenging to achieve in transistors made of these materials the off-state current levels required by the ITRS roadmap for transistors with less than 9 nm of gate length. As an alternative to these narrow bandgap and low effective mass materials, our group has been investigating the feasibility of using wide bandgap materials for the n-type transistor in sub-9-nm gate length CMOS electronics. Both experimental data on 7.5 nm MoS_2 transistors as well as simulation results based on 5 nm GaN transistors will be presented in this talk. In both cases, the wide bandgap and large effective mass of the channel material significantly reduce the leakage current in these devices, making them very competitive at these dimensions.

At the same time that we are pushing the limits of Moore's law, we need to expand electronics in directions that go beyond the pure scaling required by Moore's law. For this, our group is using heterogenerous integration of a wide set of materials systems with silicon technology. For example, GaN transistors seamlessly integrated on a Silicon CMOS chip allow for integrated power conversion and wireless amplifiers, which could save up to 30% of the energy currently dissipated in Si CMOS microprocessors. The use of two-dimensional (2D) materials like graphene and MoS_2 also allow seamless integration on a Silicon chip of new functionalities like chemical sensors and infrared bolometers.

In summary, new materials will be key for the future of digital electronics, both as channel materials in CMOS circuits, as well as seamless add-ons for enhanced performance. In this talk, we will review some of the early results on the use of GaN, MoS_2 and graphene in a beyond 5-nm technology node.

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