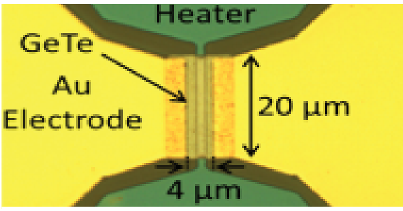
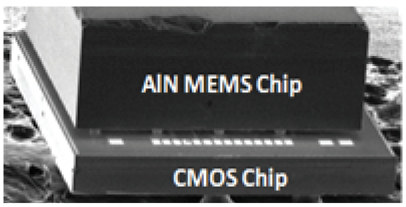
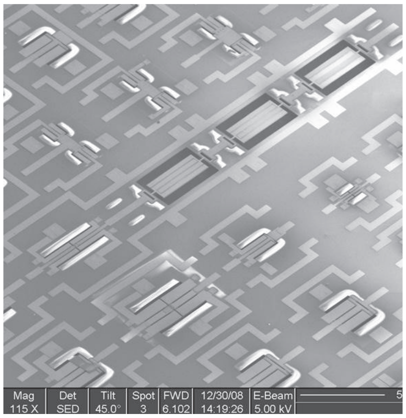
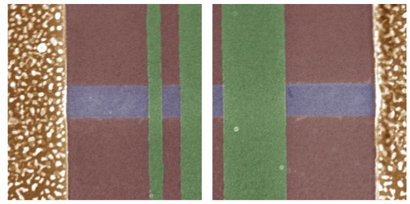
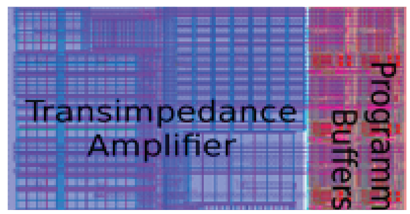
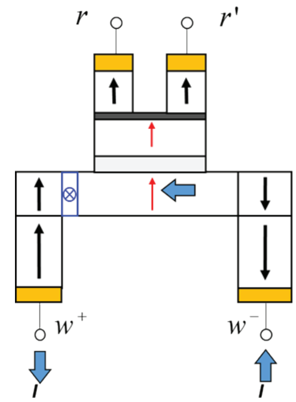
Beyond CMOS

Electrical & Computer Engineering





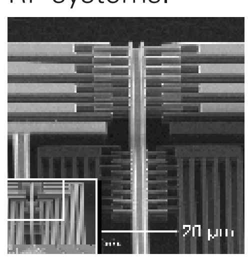
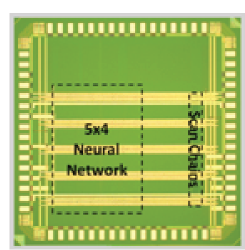


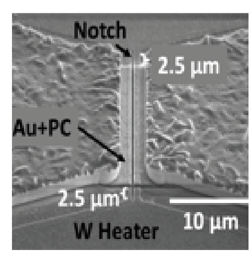
Electronics have become integral parts of our daily lives. According to the United Nation's International Telecommunication Union, in 2014 there were approximately as many cellular phone subscriptions as people on the earth (seven billion). In addition, nearly half of the world's population is using the internet. Electronics have fundamentally changed the way humans communicate and access information. This explosive growth has largely been fueled by the high performance, low cost and small form factor of the underlying integrated circuits.

In 1965 Gordon Moore famously predicted the exponential growth in the number of components per integrated circuit (Moore's Law), which was realized by decreasing device size. For decades, this scaling of classical semiconductor technologies based on complementary metal oxide semiconductor (CMOS) devices has been a driving force in the electronics industry. Although Moore's Law and traditional CMOS scaling is likely to continue in the near term, scaling limits are approaching based on both fundamental physical effects and increasing cost. These scaling limits have motivated the need for new, beyond-CMOS technologies, which can serve to continue the exponential performance improvements.

While scaling of CMOS technology may be reaching an end, due to the combination of its low cost and high performance, CMOS will likely remain the foundation upon which new hybrid systems are built. These hybrid systems will incorporate CMOS and beyond-CMOS technologies to improve system performance. Therefore, beyond-CMOS research aims to create technologies that complement CMOS rather than replace CMOS using an approach that balances system-level needs with device-level capabilities. This holistic approach necessitates a deep understanding of the interwoven relationships between the device fabrication and function, and higher-level circuit or system function.

The research in beyond-CMOS technology in ECE aims to enable future, high-performance, hybrid systems. Our research spans a range of ideas including magnetic devices, MEMS, resistive-switching electronics and devices based on 2-dimensional materials. In addition, we are investigating circuits and architectures that leverage the unique characteristics of these devices. Target applications include next-generation computing, memory, sensing, energy regulation, and reconfigurable RF systems.



Electrical & Computer ENGINEERING

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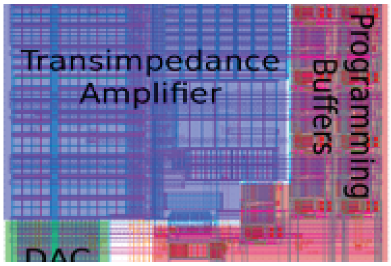
ECE expertise

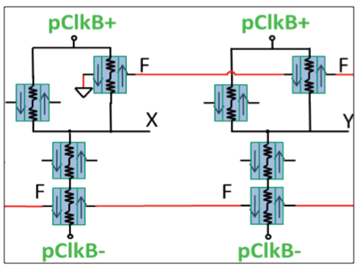
The expertise in ECE includes novel, beyond-CMOS device design and fabrication, device modeling, and circuits and architectures that leverage the unique characteristics of beyond-CMOS devices. Devices are fabricated in the Carnegie Mellon nanofabrication facility and characterized in on-campus facilities.

Circuits and architectures



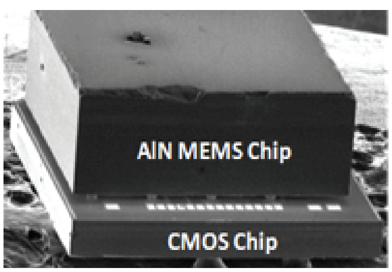
Circuits and architectures are being explored that leverage the unique characteristics of beyond-CMOS devices. These systems include circuits based purely on emerging devices and hybrid circuits, where traditional CMOS technology is combined with an emerging technology. We are investigating architectures based on massively-parallel, brain-inspired computing techniques for applications such as image processing and pattern recognition. Our research also includes circuits for low-power computing based on beyond-CMOS devices and hybrid circuits for radio-frequency systems. *Contact Larry Pileggi, Jeff Weldon, Jeyanandh Paramesh*

Magnetic logic



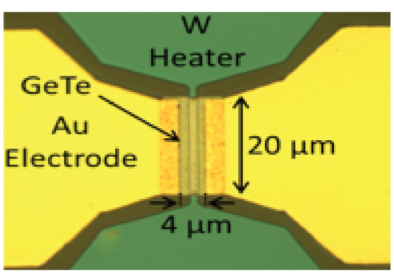
Logic based on novel magnetic devices, termed mLogic, is a proposed technology for future electronic systems in energy-constrained environments. Logic circuits are designed using all-magnetic devices with no semiconductor integration, making every single logic gate its own non-volatile storage element. mLogic systems can be powered by ultra-low voltage (sub-100 mV), noisy and even intermittent supplies, and are 3D stackable for high density logic and memory. *Contact Larry Pileggi, Jimmy Zhu*

Nano/MicroElectroMechanical systems (N/MEMS)



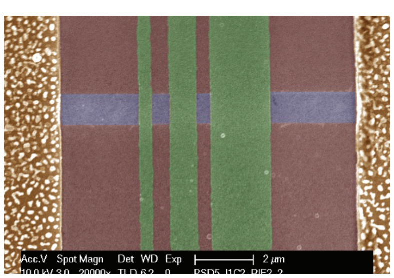
ECE has significant expertise in the area of CMOS-integrated and piezoelectric Nano/Micro-ElectroMechanical Systems (N/MEMS). Extensive fabrication capabilities in post-processing of CMOS-MEMS chips are complemented with design knowledge for electrothermal and electrostatic actuators, inertial sensors, infrared detection, and radio frequency (RF) tunable passives. Similarly, highly specialized techniques for deposition and patterning of piezoelectric thin films of aluminum nitride and lithium niobate for the making of RF resonators, filters, oscillators, and NEMS actuators and sensors are available and are being integrated with CMOS. *Contact Gary Fedder, Tamal Mukherjee, Gianluca Piazza*

Resistive switching electronics



Resistive switching materials and devices offer a host of new functionalities to traditional CMOS: memory cells, two-terminal non-linear selection devices, RF-signal switches, relaxation oscillators, and overvoltage protection devices are some applications. Materials include simple metal oxides (TiO_2, Ta_2O_5, HfO_2, VO_2, NbO_2) and phase change chalcogenides (GeTe, GeSbTe, etc.). *Contact: Jim Bain, Jeff Weldon*

Devices based on 2D materials



Two dimensional materials, such as graphene, offer unique electrical and optical characteristics that can be harnessed to create novel devices. The research in ECE aims to fabricate electronic devices based on graphene and other 2D materials, and model these devices for use in hybrid CMOS circuits. We are exploring applications such as neural networks, next-generation computing, and photonics. We have expertise in growth, fabrication and characterization of these devices, enabled by our state-of-the-art nanofabrication facility.
Contact: Jeff Weldon, Elias Towe, Randy Feenstra