Keynote
Nano-MOS - Foundation of Quantum Computing

Andrei Vladimirescu[1,2]

[1]Delft University of Technology, Delft, The Netherlands
[2]University of California, Berkeley, CA

Abstract: Advances in semiconductor and superconductor technology have sparked a new round of research in quantum computing in recent years. Quantum computers hold the promise to efficiently solve problems that are intractable by today's electronic computers. In a quantum computer, standard logic bits '1' and '0' are replaced by quantum states $|0\rangle$ and $|1\rangle$ referred to as quantum bits (qubits). The challenge facing researchers is controlling and detecting these quantum states, which are preserved long enough only at deep sub-Kelvin temperatures.
Physical qubits in existing quantum processors are implemented as either the spin of an electron or the state of a superconducting resonator (Josephson Junction). Semiconductor materials are used for most implementations. This talk will make the case for the advantages of electron spin qubit implementations when all layers of a quantum computer are considered.
In addition to the physical qubits representing the core of the quantum processor, performing operations on qubits requires an electronic interface for their control, which today is implemented with standard instrumentation placed at room temperature. This may work as proof of concept for the low number of qubits available today; however, as the race for increasing the number of qubits is on with 100 likely achievable this year, the number of qubits will grow to hundreds of thousands or maybe millions as needed for the solution of practical problems, making room-temperature electronics for control unworkable due to the wiring requirements, signal integrity and cost.
The solution is to build the control electronics to operate at 4 K or below close to the qubits; Standard CMOS is the obvious technology of choice allowing both cryogenic operation (4 K down to 100 mK) and the integration on a single chip of the billions of transistors required to operate a very large number of qubits.
The challenges and feasibility of building integrated circuits (IC) operating at 4 K and below will be described in this presentation. All aspects will be considered starting with the operation of semiconductor devices at cryogenic temperatures and the physics governing this behavior, the development of compact device models reproducing the physical behavior, the CMOS IC design methodology in conjunction with the qubit behavior, and the implementation and measurement of state-of-the-art sense and control ICs operating at 4 K. These circuits and systems must satisfy very stringent requirements for precise control of the qubit state and sensing tiny electrical signals with extreme accuracy while operating under a strict power budget below 1 mW/qubit imposed by the cooling limits of existing refrigeration technology.