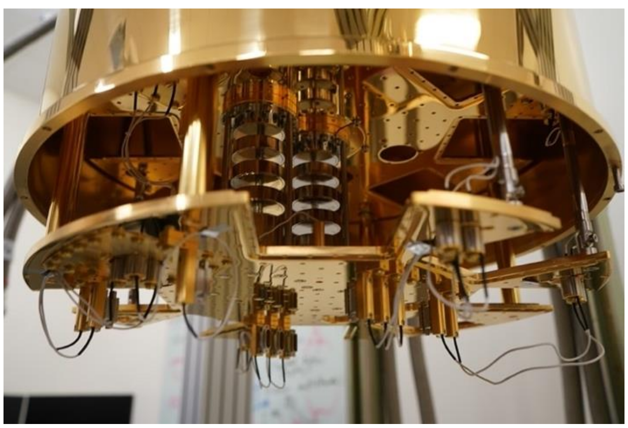
Quantum Computing

Quantum computing presents a new computing paradigm that harnesses the power of quantum physics to solve complex problems exponentially faster than conventional compute. It promises to revolutionize industries and solve critical problems involving climate change, chemical engineering, drug design and discovery, finance, and aerospace design. While there have been many developments, there are major challenges that must be solved to realize its full potential.



Quantum computing employs the properties of quantum physics like superposition and entanglement to deliver the ultimate in parallel computing. Traditional transistors use binary encoding of data represented electrically as "on" or "off" states. Quantum bits or "qubits" can simultaneously operate in multiple states enabling unprecedented levels of parallelism and computing efficiency. However, qubits are tremendously fragile. Any radio frequency noise or unintended observation can cause data loss. To eliminate noise, qubits must operate at a temperature of approximately 20 millikelvin – or 250 times colder than deep space.

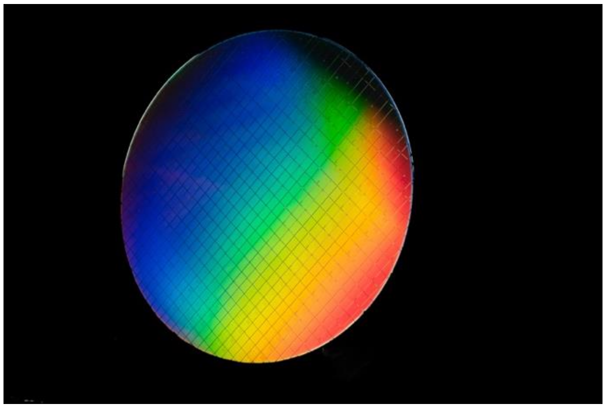
While quantum computers promise greater efficiency and performance to handle certain problems, it will take a massive amount of computing power to design, model, build and operate these systems. In addition, they won't replace the need for conventional computing. As the complexity of workloads and applications continues to grow, quantum computing will *augment* supercomputers and high-performance computing (HPC). A large-scale supercomputer or substantial classical compute infrastructure will run applications resulting in a "hybrid" quantum/classical model.

Currently, quantum systems only include tens or hundreds of entangled qubits, in which two members of a pair of qubits exist in a single quantum state. To achieve commercial relevance, quantum systems need to scale to over a million qubits and overcome daunting challenges, like qubit fragility and software programmability. While there have been many recent developments, Intel believes the industry is still about 10 years from large-scale commercial implementation.

Intel's Vision for Quantum Computing

Intel has invested heavily in quantum computing research over the past decade and is taking a full-systems architecture approach that spans the complete compute stack from qubit architecture and algorithms research to control electronics, interconnects, quantum software toolchains and compilers, continuing all the way to the application layer. In addition, Intel has a role in both quantum and HPC technology and is uniquely positioned to lead the way in developing a whole system architecture as this nascent technology evolves.

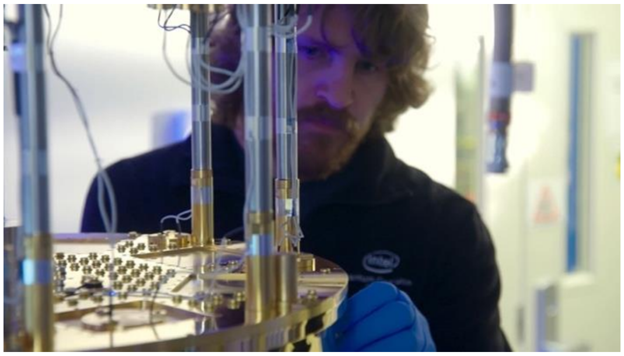
There are several approaches to quantum computing, but Intel is leveraging its deep expertise in silicon transistor design, high-volume manufacturing and advanced fabrication technologies to create "hot silicon spin qubits."



These qubits are much smaller computing devices that operate at high temperatures and behave in ways analogous to transistors.

Intel is focusing on finding ways to build silicon spin qubits on silicon wafers and is working on advancing qubit manufacturing process technology. In April 2022, a collaboration between researchers at Intel and QuTech resulted in the discovery of a qubit manufacturing process that fabricated more than 10,000 arrays with several silicon-spin qubits on a single wafer with greater than 95% yield. This groundbreaking research demonstrates that qubits could eventually be produced in the same manufacturing facilities alongside conventional microprocessors and provides a step forward toward scaling quantum chips.

At the hardware level, Intel has developed a customized test chip for spin qubits, the second-generation Horse Ridge II cryogenic control chip and designed a new tool called the cryoprober to test and characterize these 300-millimeter silicon spin qubit wafers at scale to speed research and accelerate commercialization. At the software level, Intel released an open-source beta version of the Intel Quantum Software Development Kit (SDK) available on Intel DevCloud, enabling developers to begin programming for quantum applications and explore future uses of the technology on Intel hardware.



Intel is also committed to developing the entire quantum industry ecosystem across the compute stack. The company has several collaborators in academia and works closely with the Delft University of Technology (TU Delft) and the Netherlands Organization for Applied Scientific Research (TNO), as well as government agencies including Q-NEXT, led by the U.S. Department of Energy's Argonne National Laboratory. In addition, Intel's director of quantum hardware serves on the board of the White House Office of Science and Technology Policy (OSTP) and the U.S. Department of Energy's (DOE) National Quantum Initiative.

Post Quantum Cryptography

While quantum computers are still years away, there are several threats to consider today. The goal is to be "Y2Q" ready by 2030, as adversaries are already harvesting data and saving encrypted data today with the intention of breaking encryption in the future. To prepare for this, Intel has created a phased approach for post-quantum cryptography (PQC). It includes increasing the robustness of Intel products to help establish quantum-resistant root-of-trust and engaging with standards bodies such as the National Institute of Standards and Technology (NIST) to develop, harden and accelerate technologies to secure web transactions.

What's Next?

Intel's quantum computing vision focuses on quantum practicality and scalability to bring quantum out of the lab and into commercial reality. Intel's researchers are truly excited about the possibilities ahead. They remain steadfast in Intel's journey to help break down the technological barriers and apply expertise to make a large-scale quantum compute system, and ultimately realize quantum's full potential.