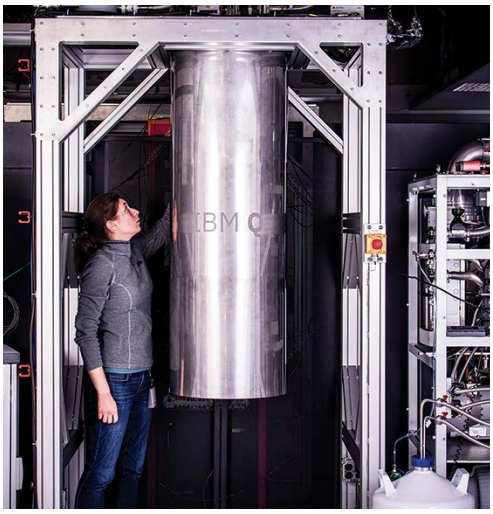

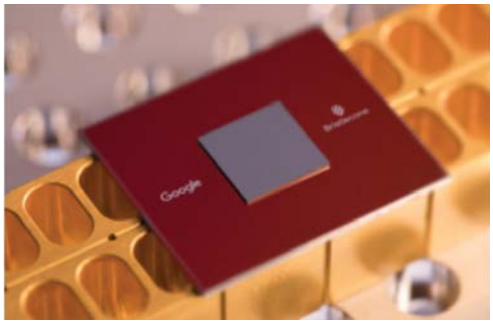

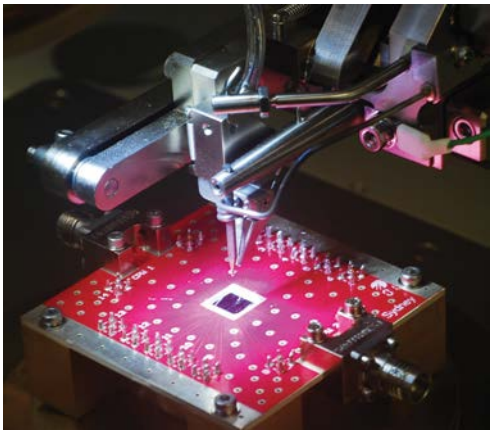

ABOUT THE IMAGES

An IBM researcher examining a cryostat cooling cylinder that contains a prototype of a commercial quantum processor.
(IBM)

Google's newest 72 qubit quantum processor is being tested for applications in quantum simulation and artificial intelligence.
(GOOGLE)

Topological materials that create quantum effects through novel semiconductor structures such as those being worked on here offer one possible route to quantum computing.
(MICROSOFT)

The *EMERGING TECHNOLOGY* of **QUANTUM COMPUTING**

Quantum computers will have unique abilities for certain types of problems, such as breaking codes. That's why national security agencies are intensely interested. These computers will also be able to search massive databases at unparalleled speed, which is why major corporations interested in artificial intelligence are also interested and are pursuing several different approaches to building practical data processing devices. What underlies these efforts is several decades of research—supported by the Basic Energy Sciences (BES) office of DOE—on materials that exhibit multiple quantum states.

The Breakthrough

The BES-funded discovery in 1985 of multiple quantum states in a manmade superconducting device. Subsequent fundamental research led to additional materials that display this phenomenon. Today, candidate data processing devices, known as quantum bits or qubits, are being developed from these types of materials. These include:

- Superconducting loops in which a current oscillates back and forth, now being pursued by Google and IBM.
- Topological materials, which exhibit quantum effects in semiconductor structures, being pursued by Microsoft and Bell Laboratories.
- Quantum dots, which trap a single electron in a tiny silicon crystal, being pursued by Intel.

The Impact

The emergence of practical quantum technologies will transform computing and communications and enable measurement devices of unparalleled accuracy.

- Quantum measurement devices known as SQUIDS can already detect magnetic fields 100 billion times smaller than the magnetic field from an ordinary refrigerator magnet and have been used for mineral prospecting and to image the magnetic fields from human brains. Advanced quantum sensors will have even greater accuracy.
- Quantum computers with 100 qubits such as those described above—which some experts believe may be achieved in the near future—are the threshold for capabilities to solve certain types of problems that cannot be matched by any imaginable conventional computer.
- Quantum communications could provide uniquely secure and unhackable ways to transmit data.

The Takeaway

Multiple decades of fundamental research, supported by BES but not directly focused on quantum computing, seems likely to pay a big dividend.

Adapted from chapter 9 of A Remarkable Return on Investment in Fundamental Research, U.S. DOE, June 2018.
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