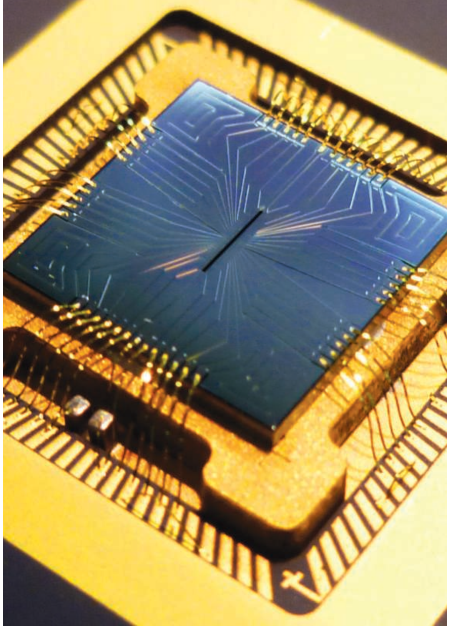

PHOTO: CURT SUPLEE AND EMILY EDWARDS, JOINT QUANTUM INSTITUTE AND UNIVERSITY OF MARYLAND; CHIP FABRICATION: SANDIA NATIONAL LABORATORIES WITH SUPPORT FROM THE INTELLIGENCE ADVANCED RESEARCH PROJECTS ACTIVITY

INTRODUCTION

The Future of Quantum Information Processing

IN A WORLD OVERWHELMED BY INCREASING AMOUNTS OF DATA, FINDING NEW WAYS to store and process information has become a necessity. Conventional silicon-based electronics has experienced rapid and steady growth, thanks to the progressive miniaturization of its basic component, the transistor, but that trend cannot continue indefinitely.

In conventional devices, information is stored and manipulated in binary form: The elementary components of these devices—the so-called bits—have two states, each of which encodes the binary 0 or 1. To move beyond the binary system, one can exploit the laws of quantum mechanics. A quantum-mechanical object with two energy levels at its disposal can occupy either of those two levels, but also an arbitrary combination ("superposition") of the two, much like an electron in a two-slit experiment can go through both slits at once. This results in infinitely many quantum states that a single quantum bit, or "qubit," can take; together with another strange property of quantum mechanics—entanglement—it allows for a much more powerful information platform than is possible with conventional components.

Quantum information processing (QIP) uses qubits as its basic information units. QIP has many facets, from quantum simulation, to cryptography, to quantum computation, which is expected to solve problems more complex than those within the capabilities of conventional computers. To be useful for QIP, a qubit needs to be both isolated from its environment and tightly controllable, which places stringent requirements on its physical realization. But this is only the first step; to build a quantum computer, for example, we must also have a scalable architecture and error correction that can be performed in parallel with computation; in addition, efficient quantum algorithms must exist for solving the problem at hand—a considerable theoretical challenge.

A number of qubit types have been proposed and experimentally realized that satisfy at least some of these criteria, and tremendous progress has been made over the past decade in improving the figures of merit, such as the coherence time. In this special section, four Reviews look into the future of QIP in some of its most promising physical realizations. On p. 1164, Monroe and Kim discuss the challenges of scaling trapped ion architectures to hundreds and thousands of qubits and beyond. Devoret and Schoelkopf (p. 1169) speculate on the future of superconducting circuits, whereas Awschalom *et al.* (p. 1174) focus on the many promising qubit flavors based on spins in semiconductors. Finally, Stern and Lindner (p. 1179) lay out the prospects for quantum computation using the entirely different approach of topologically protected states.

The future of QIP appears bright in spite of the many remaining challenges. As a bonus, overcoming these challenges will probably also advance basic research.

– JELENA STAJIC

Online
sciencemag.org
Podcast interview with author D. D. Awschalom (http://scim.ag/pod_6124a).

Quantum Information Processing

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The Future of Quantum Information Processing

Jelena Stajic

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