Fabricating qubits using advanced semiconductor manufacturing processes

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FIGURE

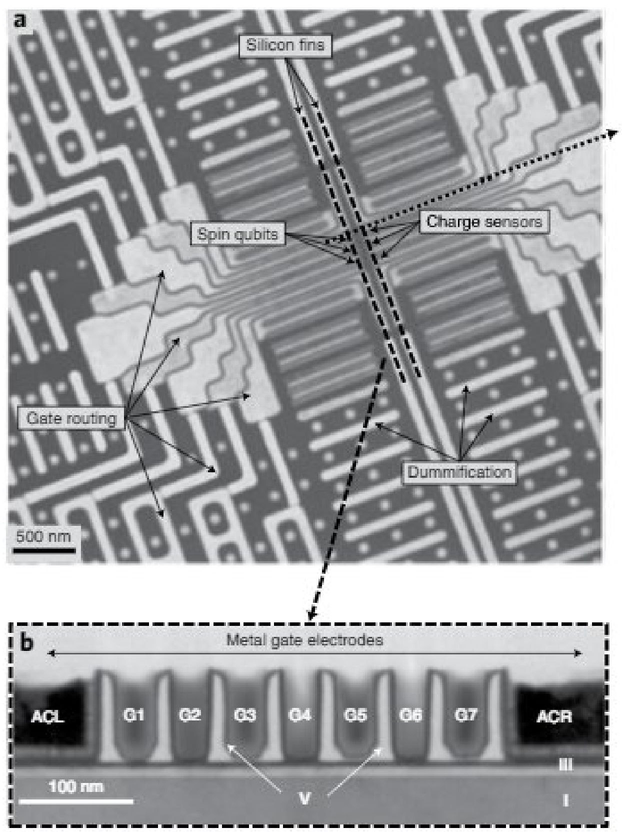

Fig. 1 | Industrially fabricated spin qubit devices. a, Plan-view transmission electron microscopy (TEM) image of a silicon metal–oxide–semiconductor-based spin qubit test structure fabricated in a manufacturing facility that produces 300-mm semiconductor wafers. The key features of the device are highlighted. **b**, Cross-section TEM image of the active qubit fin highlighting the various gate electrodes used to create individual electrons and control the tunnel coupling between them. G*n*, gates ($n = 1$–7); ACL, left accumulation gate; ACR, right accumulation gate; I, silicon; III, composite SiO_2 and high-*k* dielectric; V, SiO_2 interlayer dielectric. © 2022, Zwerver, A. M. J. et al., CC BY 4.0.

Credit: *Nature Electronics*, Zwerver et al.

Quantum computers are promising computing machines that perform computations leveraging the collective properties of quantum physics states. These computers could help to tackle many computational problems that are currently intractable with conventional computers.

Despite their promise, fabricating quantum computers on a large-scale is currently very challenging, as a full-scale quantum computer integrates millions of qubits. To ensure that they can be produced using industrial semiconductor manufacturing processes, quantum device engineers have been trying to create quantum computers based on silicon quantum dots.

Nonetheless, existing quantum computers have been primarily fabricated using electron-beam lithography and conventional lift-off processes. This greatly limits their production rates, as both these processes only yield a few properly functioning devices at a time.

As part of a recent study, researchers at Delft University of Technology (TU Delft) and Intel Corporation successfully fabricated quantum dots at a $^{28}Si/^{28}SiO_2$ interface using alternative and advanced processes, at an Intel semiconductor manufacturing facility. Their paper, published in *Nature Electronics*, demonstrates the feasibility of building full-scale quantum devices relying on the current manufacturing infrastructure.

"This work builds on twenty years of exploratory research in semiconductor spin qubits at QuTech, and on many decades of advanced semiconductor manufacturing development at Intel," Lieven Vandersypen, one of the researchers at TU Delft, told *Tech Xplore*. "The primary objective was to unite these two worlds in a joint research project, realizing semiconductor qubits using Intel's advanced manufacturing facilities."

The researchers' silicon quantum dots were fabricated at an Intel facility, using all-optical lithography and fully industrial processing processes. Optical lithography, also known as photolithography, is a manufacturing technique used to transfer a pattern onto a substrate using a photosensitive material.

"We leveraged our transistor manufacturing expertise to create a customized research and development line for qubits," Ravi Pillarisetty, a Quantum Device Engineer at Intel, told TechXplore. "This allows us to tap directly into our rich history of process innovations that have driven Moore's law over the last 50 years."

The recent work by this team of researchers shows that fabricating uniform and reliable qubits on a large-scale, using existing manufacturing processes, is possible. The qubits they created are directly compatible with the advanced interconnect and circuit design schemes that are associated with the current manufacturing of semiconductors.

"For years, the community has claimed that semiconductor spin qubits can leverage the extensive know-how and technology of the electronics industry," Vandersypen said. "In this work, we finally show this is true. Being able to leverage this technology boosts the prospects of creating millions of qubits that all work."

In the future, the recent work by Vandersypen, Pillarisetty and their colleagues could pave the way towards the large-scale and reliable manufacturing of qubits for quantum computers and other quantum technologies. Meanwhile, the team at Intel and TUDelft plans to explore ways in which the manufacturing processes they used could be optimized further.

"Our research and development line allows us the capability to run high volume experiments to understand how our process can be modified to improve qubit performance and quality," Pillarisetty added. "Additionally, we are leveraging our CMOS infrastructure to identify pathways to scale to large size qubit systems."

More information: A. M. J. Zwerver et al, Qubits made by advanced semiconductor manufacturing, *Nature Electronics* (2022). DOI: 10.1038/s41928-022-00727-9