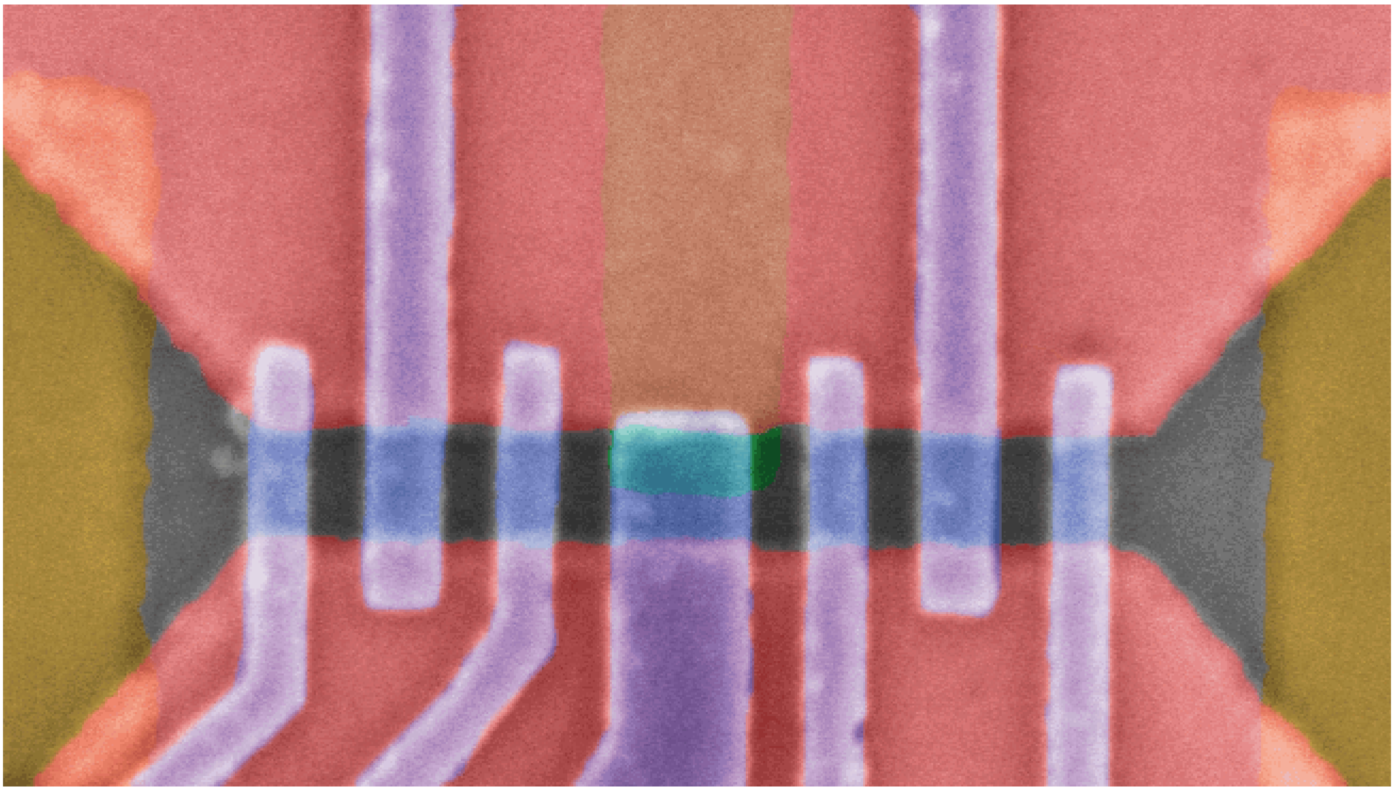
physicsworld

QUANTUM COMPUTING | RESEARCH UPDATE

‘Poor man’s Majoranas’ offer testbed for studying possible qubits

08 Jul 2024



Platform for Majorana research: A scanning electron micrograph of a nanodevice that was measured to obtain results presented in the latest QuTech research. (Courtesy: TU Delft)

Majorana particles could be an important component in quantum computers – if they exist. Using a new approach, physicists at QuTech in the Netherlands say they have now found fresh hints that Majorana-type behaviour is possible. They have also devised an experimental testbed for studying the properties of these particles and determining whether they live up to expectations.

Quantum computers use phenomena such as superposition to solve problems that would be impossible for classical machines. However, the quantum mechanical states they use for their computations are fragile. These states are known as quantum bits, or qubits, and they easily decohere, meaning that they lose their quantum nature and thus their ability to perform calculations. This is true for all existing qubit platforms, including trapped ions, spin qubits, superconducting qubits, Rydberg atoms and others. The only way of avoiding decoherence is to keep these quantum systems extremely stable, which requires equipment that is bulky, expensive and complex.

One possible alternative is to make qubits from so-called Majorana bound states (MBSs). These states are quasiparticles that arise from collective effects in a superconducting system, and they are protected from decoherence by the system’s topology – for example, by being bound to opposite ends of a nanoscale wire. This stability could make it possible to perform quantum computations with fewer qubits, but MBSs are notoriously difficult to produce. Only a handful of labs have seen positive hints of their existence, and past claims about Majoranas have produced intense debate within the scientific community. Several once-promising results have become the subject of expressions of concern or retractions, including two *Nature* papers co-authored by researchers at QuTech (which is a collaboration between the Delft University of Technology and TNO, the Netherlands’ organization for applied science research).

A new route

In the latest work, which is also published in *Nature*, a different team at QuTech produced MBSs by coupling two spin-polarized quantum dots in a semiconductor-superconductor hybrid material. The coupling occurs via so-called Andreev bound states, which can be seen as a superposition of electrons and holes. By controlling these states using magnetic fields and gate voltages, the researchers tuned the system to “sweet spots” that demonstrate correlated zero-bias conductance peaks (ZBPs), which are an important property of MBSs and are resilient in the face of local perturbations.

However, because these experiments use only two quantum dots, the MBSs that arise are not topologically protected. These states have therefore been nicknamed “poor man’s Majoranas”, and the QuTech researchers aim to use them as a platform to study how the protection of Majoranas evolves as the number of sites in a so-called Kitaev chain increases.

Key experiments

The researchers performed two key experiments to verify the Majorana-ness of their system. In the first, they isolated Majorana pairs from each other and showed that disturbing one leaves the other unaffected, demonstrating that the ZBPs are indeed protected from local disturbances. In the second, the team estimated the Majorana polarization, which is an important metric for the quality of MBSs and is key to using them in qubits, which require multiple MBSs.

Srijit Goswami, the QuTech physicist who led the latest study, says that realizing these Kitaev chains in a two-dimensional platform is an important step towards the systematic study of MBSs. Disorder and impurities in these devices, he explains, sometimes create strong electrical fluctuations that would not be desirable in scalable qubits. Though these fluctuations do not undermine the physics of the experiment, Goswami acknowledges they need to be tackled before working towards more complex devices. “In order to realize a qubit, we must first understand the primary decoherence mechanisms for Majorana-based qubits,” he tells *Physics World.*

Debating Majoranas

Sankar Das Sarma, a theorist at the University of Maryland, US, who has collaborated with QuTech scientists in the past but was not involved in this work, describes the result as good for basic research, but emphasizes that an expansion to many-dot experiments will be necessary to create a workable technology. He also expresses some uncertainty as to whether the team’s approach – using quantum dots rather than nanowires, as previous experiments did – could lead to Majorana modes with exponential topological protection. The team’s biggest achievement, he says, is fabricating the sample and doing the experiment.

Henry Legg, a theorist at the University of Basel, Switzerland, who was likewise not involved in this research, says it is nice to see new device fabrication on new platforms. However, he suggests that the team may, in fact, have observed other, less interesting states that resemble Majorana bound states (MBSs), but lack the necessary topological protection. Such states would not have any advantage over other platforms such as superconducting or spin qubits, he explains, adding that the result has no proven relevance to the ultimate goal of a true MBS. The main challenge in this field, he says, is to overcome the impact of disorder, and it is not clear that producing a true Kitaev chain from these building blocks will do that.

Two critics of previous QuTech research on Majoranas are also not convinced. Vincent Mourik of Germany’s Forschungszentrum Jülich points out that the retracted QuTech Majorana work contained undisclosed data manipulations, including “inappropriately deleted or cropped” data in published figures. Given these earlier practices, and the similar topic, Mourik says he hoped that QuTech would adopt a policy of sharing the full data of a project upon publication. In the latest work, however, he notes that Goswami and colleagues only shared data corresponding to the published figures, not the full dataset.

Sergey Frolov, a physicist at the University of Pittsburgh, US, offers a similarly harsh judgement. “This paper, like the other two papers from Delft in *Nature* on this, do not report Majorana, present data in a very narrow way and do not advance quantum computing,” says Frolov, who co-organized an international conference on reproducibility in condensed-matter physics earlier this year. “Once we get the old data out of them, we will request this ‘poor man Majorana’ data as well,” he adds. “I think there will be things to find in the full data...Until they undergo a full external investigation, none of their results should be taken seriously.”

In response, the authors of the latest QuTech paper say that there is “no methodological connection” between this work and the work described in the previous retracted papers. “These experiments were conducted in a different research group with a different set of researchers,” they continue. “We find it deeply concerning that [Mourik and Frolov] place us, as authors of this new publication, under collective suspicion.”

The authors also state that QuTech’s data management policy “goes further than the policy of other research institutions” as QuTech publishes “at least all raw data underlying published figures, as well as the processing scripts. This was also the case for the current publication.”

- **This article was amended on 11 July to include a response from the authors**

Martijn Boerkamp is a science writer based in the Netherlands

OUR MISSION

Physics World represents a key part of IOP Publishing's mission to communicate world-class research and innovation to the widest possible audience. The website forms part of the ***Physics World*** **portfolio**, a collection of online, digital and print information services for the global scientific community.