Diamonds are a quantum computer's best friend

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A new concept for a quantum computer has been proposed.

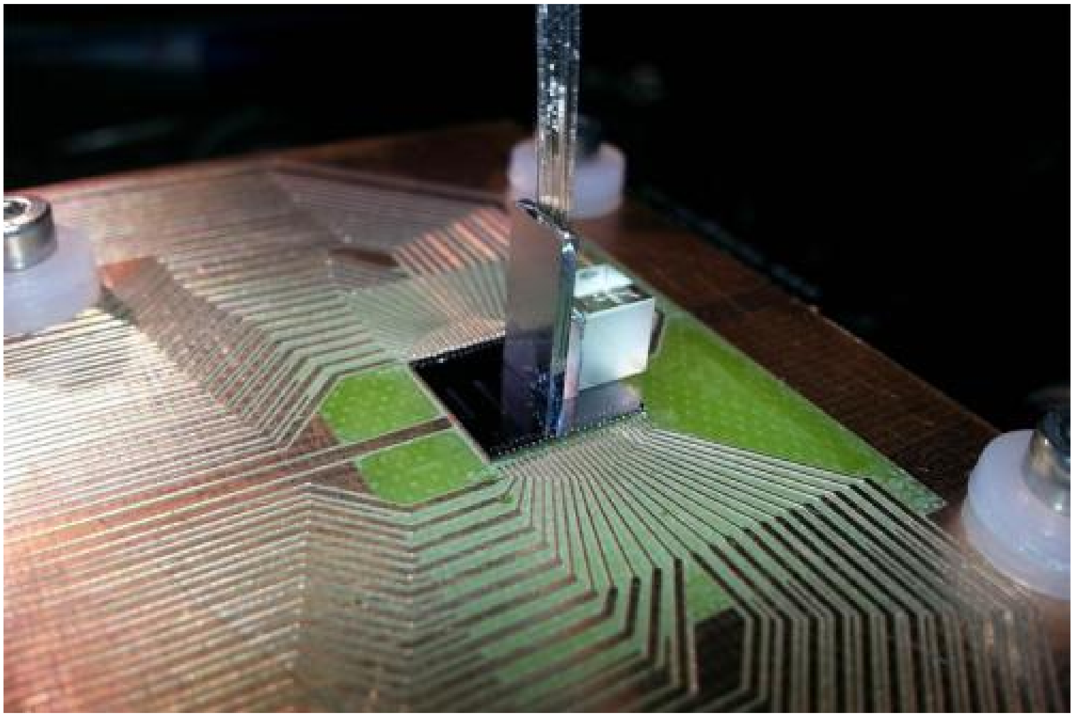
A new kind of quantum computer is being proposed by scientists from the TU Wien (Vienna) and Japan (National Institute of Informatics and NTT Basic Research Labs).

The Quantum Computer is the Holy Grail of quantum technology. Its computing power would eclipse even the fastest classical computers we have today. A team of researchers from TU Wien (Vienna) the National Institute for Informatics (Tokyo) and NTT Basic Research Labs in Japan has now proposed a new architecture for quantum computing, based on microscopic defects in diamond. A reliable quantum computer capable of solving complex problems would have to consist of billions of quantum systems, and such a device is still out of reach. But the researchers are convinced that the basic elements of their newly proposed architecture are better suited to be miniaturized, mass-produced and integrated on a chip than previously suggested quantum computing concepts. Experiments towards the new quantum computing architecture are already being undertaken at TU Wien.

Fragile Quantum Superpositions

For decades, scientists have been trying to use quantum systems for logical calculations. "In a classical computer, one bit can only store a number: zero or one. Quantum physics, however, allows superpositions of states. A quantum bit can be in the state zero and the state one at the same time – and this opens up unbelievable possibilities for computing", says Jörg Schmiedmayer (TU Wien).

Such superposition states can be implemented in different kinds of quantum systems, such as ions, captured in electromagnetic traps, or in superconducting quantum bits. The architecture which has now been published in the journal *Physical Review X* is different: nitrogen atoms which can occupy two different spin states are injected into a small diamond. Every nitrogen defect is trapped in an optical resonator made of two mirrors. Via glass fibres, photons are coupled to the quantum system consisting of the resonator, the diamond and the nitrogen atom. This way, it is possible to read and manipulate the state of the quantum system without destroying the quantum properties of the spins in the diamond.



At the Vienna University of Technology (TU Wien), experiments with nitrogen atoms in diamonds are already being carried out.

Realistic Quantum Computers Need Error Correction

Each system – made up of mirrors, diamond and a nitrogen defect – can store one quantum bit of information: zero, one, or an arbitrary superposition of both. But usually such a quantum bit is very unstable. Error correction procedures are needed to build a quantum computer that works reliably. "If error correction is used, a quantum bit cannot be stored in one single quantum particle any more. Instead, a complex architecture of interconnected quantum systems is required", says Michael Trupke (TU Wien).

The researchers calculated how the resonators, diamonds and nitrogen atoms can be assembled to create an error resistant two dimensional quantum system, a so-called "topologically protected quantum computer". According to the calculations, about 4.5 billion such quantum systems would be sufficient to implement the algorithm "Shor-2048", which is able to calculate prime factors of a 2048-bit-number.

This huge number of quantum elements is required in any quantum computer architecture, no matter whether ion traps, superconducting quantum bits or nitrogen spins in diamonds are used. "Our approach has the big advantage that we know how to make the elements smaller. This architecture has great potential for miniaturization and mass production", says Michael Trupke. "Whole industries are working with diamonds, materials science is progressing rapidly. There are still many obstacles to overcome, but connecting nitrogen spins in solid materials opens up a path that could finally lead to a functioning quantum computer."

Only the Beginning – just Like the Transistor

Trupke compares the current state of quantum computing with the early days of electronic computing: "When the first transistors were built, nobody could imagine placing them on a small chip by the billions. Today, we carry around such chips in our pockets. These nitrogen spins in diamond could develop just like transistors did in classical computer science."

At TU Wien, researchers have begun to create a small-scale realisation of this new architecture. "We have the great advantage of being able to collaborate with a number of internationally renowned research teams in materials research and quantum technology right here at TU Wien", says Jörg Schmiedmayer. Friedrich Aumayr works on methods to inject the nitrogen atoms into the diamonds, Peter Mohn obtains numerical data in large-scale computer simulations. The microcavity arrays are the result of an ongoing collaboration with Ulrich Schmid at the centre for micro- and nanostructures (ZMNS) within TU Wien. Diamond chips are routinely analysed in the university's own X-ray centre.

There may still be a long way to go before algorithms like Shor-2048 run on a quantum computer. But scientists believe that it should become possible to entangle quantum building blocks, creating larger cluster cells, within the next few years. "Once this happens, the scale-up will be fast", says Kae Nemoto of the National Institute of Informatics. "In the end," Schmiedmayer says, "it all depends on whether we manage to enter an era of mass production and miniaturization in quantum technology. I do not see any physical laws that should keep us from doing that."

More information: Original publication in *PRX*: journals.aps.org/prx/abstract/ … 03/PhysRevX.4.031022
Additional paper about the quantum technology used for the new quantum architecture: arxiv.org/pdf/1309.0023v1.pdf

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